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WATER QUALITY MANAGEMENT PLANNING FOR URBAN RUNOFF

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This manual provides technical assistance to State and local water quality management planners to enable them to quantify within reasonable limits the urban nonpoint water pollution problem in a local planning area without extensive data generation, and to make a preliminary evaluation of cost effective abatement and control practices. The manual prescribes procedures for several levels of input, each requiring more self-generated data, with increasingly sophisticated results. A state-of-the-art and an extensive bibliography on urban storm water runoff is presented in the appendix. A glossary is also included.

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EPA/WPD Review Notice

This report has been reviewed by the Water Planning Division and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

During final review two portions of the method presented herein appeared to warrant additional comment. The first concerns the selection of a design storm. The method presented allows the selection of the design storm without consulting local precipitation or hydrologic data. The local applicability of calculated results could be improved if the procedure included at least a brief survey of available precipitation data. This review of available data could result in a more accurate estimate of the volume of runoff as well as a better estimate of the frequency of occurence and the reliability of the proposed stormwater management system.

The second matter of concern involves the use of impervious area runoff for the calculation of pollutant concentration. As is stated in the manual, this assumption results in a "worst case" calculation since pervious area runoff may provide additional water for dilution. This additional volume from pervious areas should be considered particularly in study areas with steep slopes, frequent rainfall events, and relatively impervious soils.

The method presented here is intended to be used as a first approximation of the magnitude of the stormwater management problem on a local basis. Since the manual is applied to specific situations, weak as well as strong assumptions will undoubtedly become apparent and refinements of the method will be necessary.

Abstract

This manual provides technical assistance to state and local water quality management planners to enable them to quantify within reasonable limits the urban non-point water pollution problem in a local planning area without extensive data generation, and to make a preliminary evaluation of cost effective abatement and control practices. The manual prescribes procedures for several levels of input, each requiring more self-generated data, with increasingly sophisticated results.

A state-of-the-art and an extensive bibliography on urban storm water runoff is presented in the appendix. A glossary is also included.

The manual is not intended to be used as a basis for abatement design but does provide a guide to data generation for this purpose.

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INTRODUCTION

The 1972 Amendments to the Federal Water Pollution Control Act specifically require that non-point sources of water pollution be considered in the development of water quality management plans for both local and areawide planning. In the past, efforts to control water pollution were primarily focused on point sources of water pollution such as effluent discharges from sewage treatment plants and wastewater discharges from industries.

Significant gains have been made toward the control of point sources of water pollution primarily because point sources are more obvious in nature than non-point sources and are correspondingly easier to identify and characterize. The water pollution potential of non-point sources was not fully appreciated until several major studies revealed that, in many areas, urban runoff can be a more serious source of water pollution than municipal sewage discharges. During the occurrence of some storm events, runoff from street surfaces alone has been shown to contribute significantly more BOD to receiving waters than the effluent from a city's sewage treatment plant. The general quality characteristics of urban storm water runoff are described in Table 1.

Although all surface waters have a natural self-purifying capacity for assimilating water-borne wastes, an urban environment may overwhelm this natural assimilation process due to the vast amounts of pollutants entering watercourses from a centralized urban area. Consequently, a systems approach must be adopted toward water quality management planning in order to counteract the water quality impacts of urban areas. Such an approach would focus upon a specified urban area and then proceed to identify and characterize all sources of water pollution, point and non-point, within the specified area.

Table 1. CHARACTERISTICS OF STORMWATER RUNOFF

City	BOD (mg/ℓ)	Total solids (mg/ℓ)	Suspended Solids (mg/ℓ)	Coliform (number/ℓ)	Chlorides (mg/ℓ)	COD (mg/ℓ)
1. East Bay Sanitary District; Oakland, California						
Minimum	3	726	16	4	300	
Maximum	7,700		4,400	70,000	10,260	
Average	87	1,401	613	11,800	5,100	
2. Cincinnati, Ohio						
Maximum Seasonal Means	12	260				110
Average	17		227			111
3. Los Angeles County						
Average 1962-63	161	2,909			199	
4. Washington, D.C.						
Catch-basin samples during storm						
Minimum	6		26		11	
Maximum	625		36,250		160	
Average	126		2,100		42	
5. Seattle, Washington	10			16,100		
6. Oxney, England	100[a]	2,045				
7. Moscow, U.S.S.R.	186-28	1,000-3,500[a]				
8. Leningrad, U.S.S.R.	36	14,541				
9. Stockholm, Sweden	17-80	30-8,000		40-200,000		18-3,100
10. Pretoria, South Africa						
Residential	30			240,000		29
Business	34			230,000		28
11. Detroit, Michigan	96-234	310-914	102-213[b]	930,000[a]		

[a] Maximum

[b] Mean

Source: Water Pollution Aspects of Urban Runoff, APWA

The purpose of this manual is to provide state and local water quality management planners with a means of identifying and characterizing urban runoff as a non-point source of water pollution without extensive data generation. It is not intended to serve as a design manual nor as an absolute source of information on the subject. Rather, it is intended to give a general, first-glance assessment of the water quality aspects of urban runoff within a specified urban area.

The analytical procedures described in this manual are identified according to three levels of assessment: Levels I, II, and III. The level of assessment selected by the user will vary according to the required accuracy and the effort to be expended. As one progresses from Level I to Level III, the analytical procedures will require increasingly more effort but will yield correspondingly higher degrees of accuracy.

Consistent with the idea of a "manual," numerous example problems have been provided to illustrate analytical methods and procedures. In addition, an extensive annotated bibliography and an information matrix have been included to provide additional information on specific aspects of urban runoff.

A very sophisticated assessment of storm water runoff can be accomplished by utilizing the U.S. Environmental Protection Agency's Storm Water Management Model. This model is a computer system capable of simulating the quantity and quality of urban storm water runoff. Ideally, the combination of this manual and the Storm Water Management Model can provide water quality management planners with an entire spectrum of analytical tools, ranging from simple desk calculations to sophisticated computer techniques.

The initial construction of the manual was intended to provide an assessment of total runoff flowing from an urbanized area. The model selected for runoff quantity determination was developed for this purpose. However, the plasticity of data on the characteristics of runoff from pervious areas required that at this time the manual be limited to the characterization of runoff from street surfaces only. The basic model was modified for this purpose rather than adapting a more limited street runoff model. It is planned that as information becomes available, the manual could be expanded to include a characterization and quantification of runoff from the entire urban area.

Preliminary data have demonstrated that impervious surface contaminants are, by far, the predominant pollutants associated with urban storm water runoff. It should be noted that street surfaces serve as a vehicle for transporting other sources of runoff to a storm drain. Contaminants which originate from other sources often come to reside and accumulate upon street surfaces by (1) wind actions which blow contaminants onto street, (2) the evaporation of lawn irrigation runoff upon street surfaces, and (3) the evaporation of residual non-street storm water runoff upon street surfaces. (This last factor is perhaps the most important since a certain time of travel is required for non-street contaminants to reach street surfaces. Often, a storm event will cease after non-street contaminants have reached a street surface but before reaching a storm drain and consequently non-street contaminants may eventually come to reside upon a street surface either by deposition or evaporation.) Therefore, contaminant loadings found upon street surfaces include non-street contaminants.

MANUAL FORMAT

In order for the manual to be used effectively, users should familiarize themselves with its structure and content. The manual contains five principal sections and several supplemental appendices.

Section I	An Assessment of Urban Runoff Quantity and Quality This section provides analytical procedures to predict the quality, quantity, and rate of runoff resulting from street surface contaminant removal by specified storm events.
Section II	Example Problems Example problems to demonstrate the concepts and analytical procedures of Section I.
Section III	Miscellaneous Sources of Urban Runoff Pollution The preceding sections are concerned with urban runoff resulting from rainfall. This section considers other sources of urban runoff such as urban irrigation and snowmelt.
Section IV	Treatment, Abatement and Disposal of Urban Runoff Methods for treatment, abatement and ultimate disposal of urban runoff are discussed. Preceding this discussion, general criteria is provided for an evaluation of the water pollution potential of urban runoff.
Section V	State-of-the-Art Provides background information regarding major relevant studies conducted in numerous geographical locations since 1936. Emphasis is placed upon recent studies which were used in the development of this manual.

Appendix A through Appendix D	These appendices supply background information and other materials essential for the use of the manual.

Section I

AN ASSESSMENT OF URBAN RUNOFF QUANTITY AND QUALITY

Section I

AN ASSESSMENT OF URBAN RUNOFF QUANTITY AND QUALITY

1.0 GENERAL CONSIDERATIONS

This section provides a hierarchy of analytical methods to assess the water pollution characteristics of urban runoff at several levels of sophistication. The most accurate and definitive methods are the most difficult to utilize while more simplistic methods are presented to allow the user to obtain approximate estimates.

The water pollution characteristics of urban runoff are related to both the quantity and quality of runoff. The analytical methods presented in this section will enable the user to assess the quality and quantity of runoff as a function of time. Variations with respect to time are especially important if treatment, storage, or alternate methods of disposal are under consideration, since it enables one to identify the most polluted portion of the runoff.

Theoretically, the phenomenon of urban runoff can be described in a qualitative manner. Initially, contaminants accumulate upon urban land surfaces as a function of dustfall, street sweeping frequency, antecedent rainfall characteristics, etc. When a rain event occurs, the energy of dissipating raindrops dislodges contaminants from street surfaces, roof tops, and other urban sources, causing some contaminant particles to become suspended in solution. The soluble fraction of material goes into solution. Subsequently, runoff transports contaminants across urban land and into gutters and storm sewers, and eventually, runoff is discharged into receiving waters from storm sewers. The pollutant concentration is greatest at the beginning of a rainfall event and as the rainfall continues, subsequent runoff becomes less contaminated.

Therefore, summarizing the chronology of the urban runoff phenomenon:

(1) Contaminants accumulate upon urban land surfaces.

(2) A rain event dislodges and removes some contaminants from urban land surfaces.

(3) Runoff transports contaminants across urban land surfaces, into gutters, and thru storm sewers.

(4) Runoff eventually discharges into a receiving water.

The analytical methods in this section will attempt to simulate the phenomenon of urban runoff as described above. The ultimate product of this simulation will be a graphical representation of the quantity and quality characteristics of urban runoff originating from a defined study area under specified conditions. The simulation will generally consist of the following:

(1) Define an urban study area.

(2) Describe the characteristics of the study area.

(3) Estimate the amount and composition of various contaminants found upon street surfaces within the study area.

(4) Select a certain storm event which will generate runoff and remove street surface contaminants from the study area.

(5) Develop a graphical representation of the quantity and quality characteristics of runoff originating from the study area.

The step-by-step analytical procedures for accomplishing the above simulation are presented at the end of this section beginning with paragraph 7.0. The procedures are identified according to three levels of assessment, each yielding a correspondingly higher degree of accuracy.

Paragraphs 2.0 thru 6.0 of this section contain theory and support material to be utilized by the analytical procedures of paragraph 7.0. It is recommended that users of this manual make a concentrated effort to gain a basic appreciation of paragraphs 2.0 thru 6.0 (and corresponding example problems) before attempting the analytical procedures of paragraph 7.0.

2.0 DEFINITION OF A STUDY AREA

The basis for defining a study area will vary according to the requirements of the user. One may assess the water quality of urban runoff originating from an urban development, an urban watershed, or an entire urban community.

A study area may be defined as follows:

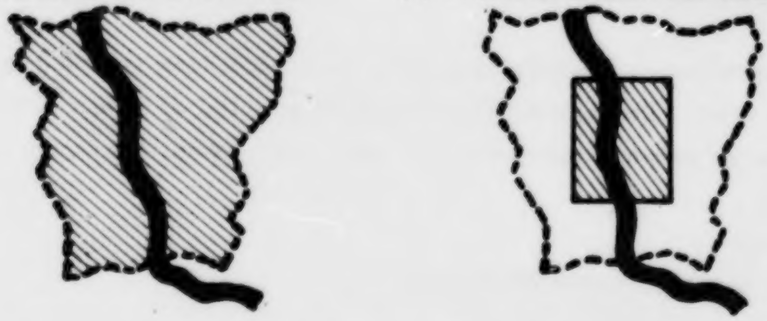
(1) An entire urban watershed (Figure 1a).

(2) A portion of an urban watershed (Figure 1b).

(3) Two or more entire urban watersheds (Figure 1c). Each individual watershed would be defined as a subarea.

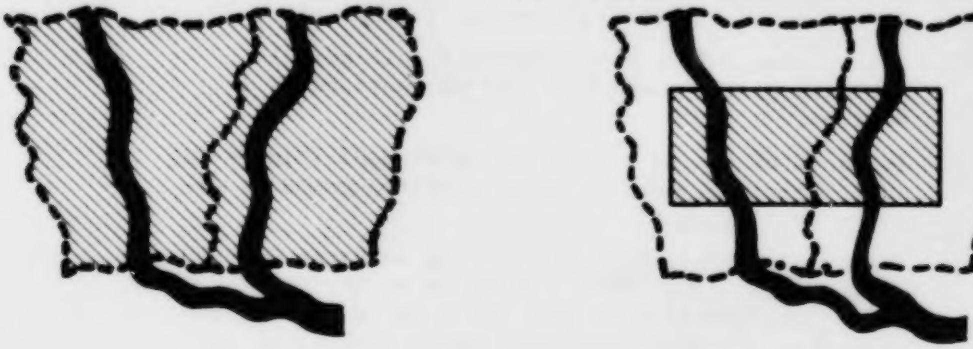
(4) Portions of two or more urban watersheds (Figure 1d). Each individual portion of a watershed would be defined as a subarea.

(5) Two or more homogenous portions of an urban watershed (Figure 1e). The study area would be divided into individual homogeneous sections with unique characteristics and each individual section would be defined as a subarea. This approach should be used when the characteristics of one portion of study area dramatically differ from the characteristics of another portion.



(a) An entire urban watershed

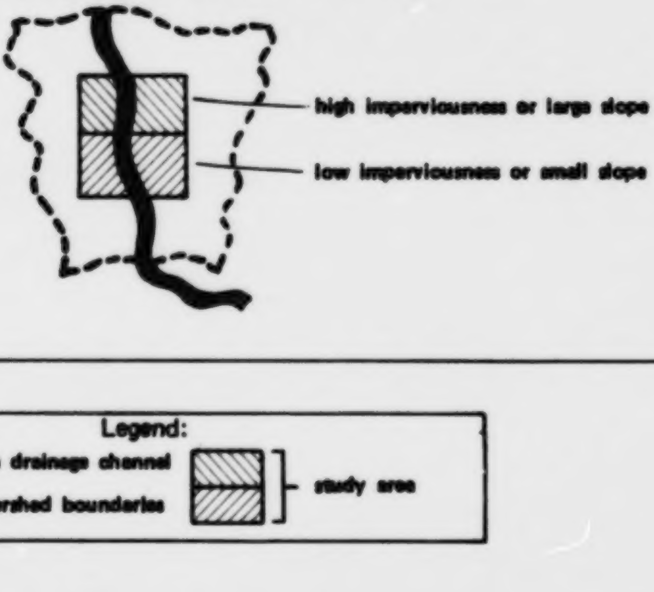
(b) A portion of an urban watershed



(c) Two or more entire urban watersheds

(d) Portions of two or more urban watersheds

(e) Two or more homogeneous portions of an urban watershed


high imperviousness or large slope
low imperviousness or small slope

Legend:

main drainage channel

- - - - watershed boundaries

▨ study area

Figure 1. Definition of a Study Area

3.0 DATA REQUIREMENTS

The analytical techniques presented in this section are such that minimal data are required. It was felt that inadequate or unavailable data should not prevent a community from using the techniques of this section. Therefore, most of the selected data parameters are readily available in most communities and can be easily approximated in others when not available. The data requirements for the analytical techniques within this section are:

- Study area characteristics
- Contaminant loading and materials composition
- Storm event characteristics and impervious runoff rate

3.1 Study Area Characteristics

Several physical characteristics of the study area are required as data by the analytical techniques presented in this section. They include:

- Size of study area (acres)
- Amount of interconnected impervious area within study area (acres)
- Amount of street surface area within study area (acres)
- Length of main drainage channel (feet)
- Average slope of main drainage channel (feet/feet)

If a study area is subdivided into two or more subareas, the physical characteristics of each subarea (i.e., subarea size, amount of interconnected impervious area within subarea, etc.) are required as data.

The amount of interconnected impervious area and street surface area can be estimated from aerial photographs or engineering maps. The estimate of interconnected impervious surfaces should not include rooftops which drain directly onto lawns, or other impervious surfaces which are not ultimately connected to a street surface via other impervious surfaces. The estimate of street surface area should include primary and secondary streets but should not include driveways, alleys, and parking lots.

The main drainage channel of a study area can be a stream, a drainage canal, or a large storm drainage pipe which traverses the study area and receives drainage from tributarial sources. Within a given watershed, smaller tributaries drain into larger tributaries which, in turn, drain into even larger tributaries. This phenomenon implies a hierarchy of tributaries which eventually drain into the main drainage channel which is the ultimate vehicle for collecting and transporting drainage from a watershed. In certain watersheds, the main drainage channel is easily identifiable as either a stream or a drainage canal flowing along the surface. However, in urban watersheds which are entirely serviced by an underground storm drainage system, the identification of the main drainage channel requires further investigation. In such a situation, the user may use a map of the storm sewer system of a study area in order to determine the specific storm drainage pipe or pipes which serve as the main drainage channel. Normally, if the main drainage channel is not readily identifiable, it can be approximated by estimating the longest distance of travel for runoff flowing thru the network of interconnected impervious areas, from the most distant point within the network to the point where collected runoff ultimately leaves the study area.

The average slope of the main drainage channel can be estimated from a topographical map of the study area as follows:

$$\text{Average Slope} = \frac{\text{Elevation Change of Main Drainage Channel}}{\text{Length of Main Drainage Channel}}$$

The general approach for describing study area characteristics is demonstrated in Example 1.

3.2 Determination of Contaminant Loading Rates and Materials Composition

The following material presents procedures and data by which a user may predict the rates of solid accumulation on urban streets and the composition of those solids. These data are based on an analysis of existing published data. The procedures used in the acquisition and processing of available data are described in detail in Appendix A. However, this section as presented is complete and can be used directly by the user to obtain the desired predictions. Appendix B describes recommended sampling procedures if the user desires to substitute actual source data for the data given in this chapter.

3.2.1 Use of the Tables

The basic tables consist of mean loading rates and solids composition in the set of all data and in 19 subsets of the whole set. The original basic statistics are shown in Appendix A/Table A-23. These statistics are condensed into Appendix A/Table A-24 from which the loading and composition tables of this section are derived.

The loading rates are expressed as pounds per curb mile per day (lb/curb mi/day), whereas later procedures make use of loads in terms of total pounds per acre of street surface. Therefore, it will be necessary for the user to initially convert the loading rate to load/curb mi, and then to convert load/curb mi to load/acre of street surface before proceeding to the following sections.

Compute the load/curb mi by the following steps:

1. Calculate the load in lb/curb mi as

   Solids Load = Rate of Accumulation X
   Equivalent Days of Accumulation

The equivalent days of accumulation (EDA) factor is necessary to account for residual amounts of pollutants left on the street after the last sweeping. This residual is considered to accumulate since the last rain, heavy enough to have removed a substantial fraction (90%) of the pollutants.

The following duration and intensities are considered heavy enough to remove 90% of road surface particulates:

- 0.1 inch/hour for 300 minutes (5 hours)
- 0.33 inch/hour for 90 minutes (1-1/2 hours)
- 0.5 inch/hour for 60 minutes (1 hour)
- 1.0 inch/hour for 30 minutes (1/2 hour)

Each of these storms results in a total rainfall of 0.5 inch. Therefore, the last substantial rainfall may be considered as one resulting in 0.5 inch of rain falling within a period of one to 5 hours. This relationship ignores the function of kinetic energy loosening street surface particulates. Therefore, deviations from the model are more substantial at lower rainfall intensities. At higher rainfall intensities, agreement with the model is much better.

The EDA is determined using the following relationship:

$$\mathrm{EDA} = (D_R - D_S)(1 - E_S) + D_S$$

where

EDA = equivalent days of accumulation
D_R = days since last substantial rainfall
D_S = days since last swept (mechanically cleaned)
E_S = effectiveness of sweeping procedure.

This relationship assumes that material began to accumulate on a surface thoroughly cleaned by the last rain and that a single sweeping operation was performed between rainfalls. Rainfalls and more than one sweeping operation occurring since the last substantial rain are not considered, but can be introduced by multiple iterative process using appropriate rainfall removal efficiencies and sweeping efficiencies. As previously indicated, a total rainfall of 0.5 inches will remove 90 percent of road surface particulates. Correspondingly, total rainfalls of .27, .15, .08, and .02 inches will remove 70, 50, 30, and 10 percent, respectively. The efficiency of sweeping practices can vary substantially by sweeper type, operational parameters and street surface particulate parameters (such as wetness and size distribution). In prior studies, URS has measured street sweeper/flusher efficiencies in a range from 11 to 62 percent removal. An average value of 40 percent is representative.

In evaluating the impacts of an assumed or hypothetical condition, it is best to ignore the rainfall effects and only use the average street sweeping frequency. This procedure can also be helpful in evaluating the effects of modifying the sweeping programs of an area (see Section IV, part C.1.), if sufficient operation parameter-effectiveness data is available.

2. Convert the solids load in lb/curb mi to lb/acre of street surface as follows:

$$\frac{\text{lb}}{\text{acre of street surface}} = \left(\frac{\text{lb}}{\text{curb mi}}\right) \times \left(\frac{\text{curb mi}}{\text{acre of street surface}}\right)$$

Equivalent curb miles per acre of street surface are shown in Table 2, arranged by land use types. However, if actual values are known, it is best to use known values.

Table 2. EQUIVALENT CURB MILES PER ACRE OF STREET SURFACE, ARRANGED BY LAND USE TYPES

Land Use Type	Equivalent Curb Miles Per Acre Of Street Surface
Open land	.53
General residential	.54
General commercial	.41
Light industrial	.43
Heavy industrial	.40
All land use types	.46

The solids composition is expressed either as micrograms per gram (equivalent to micropounds per pound) or micrograms per kilogram, conveniently referred to as parts per million (ppm) and parts per billion (ppb), respectively.

Therefore, it will not be necessary to convert the solids concentrations in the runoff water to metric units to obtain the concentrations of contaminants associated with the solids. The coliform concentrations are expressed as numbers per gram of solids (#/g). Therefore, do not express the coliform concentrations in the receiving waters as ppm or ppb, but as number/100 ml.

3.2.2 Levels of Sophistication in Using the Tables

- Level I. This level makes use of the tables in the simplest possible manner to compute the solids concentrations and the associated contaminant concentrations in the runoff water. Table 3 presents the nationwide means of solids loading rate and composition. The percent standard error of the mean indicates the degree of confidence that may be placed on the mean. This parameter is explained more fully in Appendix A.

Table 3. THE NATIONWIDE MEAN SOLIDS LOADING RATE AND COMPOSITION[a]

Lbs/Curb Mi/Day	Concentrations in Micrograms per Gram of Dry Solid								
Loading	BOD_5	COD	OPO_4	TPO_4	NO_3	NH_4	ORGN	Cd	Cr
156_b	$19,900_b$	$140,000_b$	$1,280_b$	$2,930_c$	804_b	$2,640_c$	$2,950_b$	3.4_a	211_a

Concentrations in Micrograms per Gram of Dry Solid							#/Gram	
Cu	Fe	Pb	Mn	Ni	Sr	Zn	Total Coliform	Fecal Coliform
104_a	$22,000_a$	$1,810_a$	418_a	35_a	21_a	370_a	$2.5E6_c$	$1.7E5_b$

[a] Percent Standard Error of the Mean Code: ^{a}0-9, ^{b}10-19, ^{c}20-29, ^{d}30-39, ^{e}40-49, ^{f}50-62.

The set of data available for estimating the solids composition in mercury and several pesticides is very small and unreliable. The means and standard deviations of that data are presented in Table 4. It is recommended that the planner place very little confidence in these values; they are presented primarily for informational purposes and use where it is necessary to estimate loading for these pollutants.

Proceed as follows:

1. Determine the loading rate and composition directly from Table 3. Attach the data from Table 4, if desired.

2. Convert the loading rate to load per acre of street surface as described.

3. Proceed directly to the next section wherein the load will be used. Carry the composition data along for subsequent use.

- Level II. In this level, the user can take advantage of a more detailed analysis of the available data on loading rate and solids composition. The set of all data was divided into a total of 19 subsets according to methods outlined in Appendix A. Whenever the mean of any parameter, loading rate of composition, in any subset differs "significantly" from the mean of that parameter in the set of all data, that number may be substituted for the mean of the set of all data. The method for making the determination of "significant" is described in Appendix A. Tables 5, 6, and 7 present those subset means which are different from the whole set means at the 95, 90, and 80 percent confidence levels respectively. For convenience of use, the line "All Data" is repeated in each table.

Proceed as follows:

a. Choose the level of statistical confidence permissible in substituting different values for the means of the set of

Table 4. MEAN CONCENTRATIONS OF MERCURY AND CHLORINATED HYDROCARBONS IN STREET DIRT FROM NINE U.S. CITIES

	Concentrations in micrograms per kilogram of dry solid								
	Hg	Endrin	Dieldrin	PCB	Methoxychlor	DDT	Lindane	Methyl Parathion	DDD
Mean	83	0.2	28	770	500	76	2.9	2	82
Standard deviation	111	-	28	770	1,050	118	7.1	-	78

Table 5. NINETY-FIVE PERCENT CONFIDENCE LEVEL[a]

	Category	lbs/curb mi/day Loading	Concentrations in micrograms per gram of dry solid																No./gram	
			BOD$_5$	COD	OPO$_4$	TPO$_4$	NO$_3$	NH$_4$	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TCOLI[b]	FCOLI[b]
Land Use	10 Open space																			
	20 Residential			$82,000_b$					$1,800_a$											
	30 Commercial	74_c	$58,700_c$						$6,430_a$					$3,400_b$						
	40 Light industry																			
	50 Heavy industry																		$8.2E5_e$	
Climate	1 Northeast										139_b			870_c		21_c		260_b		$4.4E5_c$
	2 Southeast				$2,240_a$											21_b				$7.0E4_d$
	4 Southwest	50_c			470_b							78_a				57_b	15_a			
	5 Northwest	30_c											$34,500_b$				10_c	480_a	$6.8E5_f$	$1.1E4_f$
Average Daily Traffic No./day	< 500																	252_b		
	500 - 5,000		$9,500_e$				419_b							$1,060_c$		17_d				$3.4E5_d$
	5,000 - 15,000																			
	> 15,000																		$3.8E5_e$	
Type of Landscaping Beyond the Sidewalk	1 Grass																		$8.3E5_d$	$7.4E4_d$
	2 Trees	43_b																	$1.1E7_b$	
	3 Landscaped buildings																			
	4 Hard surfaces						461_b										16_a		$7.1E5_c$	
Street Surface Material	1 Asphalt				$2,470_a$				$1,770_b$											
	2 Concrete	38_b	$72,000_c$		$3,520_b$		$2,600_b$		$6,680_b$											
	All data	156_b	$19,900_b$	$140,000_b$	$1,280_b$	$2,930_c$	804_b	$2,640_c$	$2,950_b$	3.4_a	211_a	104_a	$22,000_a$	$1,810_a$	418_a	35_a	21_a	370_a	$2.5E6_c$	$1.7E5_b$

---

[a] Only those subset means are shown which differ from the means of the set of all data at the 95-percent confidence level (Student $t \geq 2.25$, Degrees of Freedom > 10). Total number of permitted substitutions = 47. Percent Standard Error of the Mean Subscripting Code: a = 0 - 9, b = 10 - 19, c = 20 - 29, d = 30 - 39, e = 40 - 49, f = 50 - 62.

[b] Coliform counts are expressed in computer notation, i.e., $E5 = 10^5$.

Table 6. NINETY PERCENT CONFIDENCE LEVEL[a]

	Category		lbs/curb mi/day	Concentrations in micrograms per gram of dry solid																No./gram	
			Loading	BOD_5	COD	OPO_4	TPO_4	NO_3	NH_4	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TCOLI[b]	FCOLI[b]
Land Use	10	Open space																			
	20	Residential			$82,000_b$	850_b				$1,800_a$											
	30	Commercial	74_c	$58,700_c$	$269,000_c$			$1,580_c$		$6,430_a$					$3,440_b$				520_b		
	40	Light industry																			
	50	Heavy industry													$1,160_c$					$8.2E5_e$	
Climate	1	Northeast								$5,970_c$	2.6_b	139_b			870_c	363_a	21_c		260_b		$4.4E5_c$
	2	Southeast	103_b			$2,240_a$				$1,970_a$					$1,370_b$		21_b				$7.0E4_d$
	4	Southwest	50_c			470_b						241_a	78_a		$2,520_b$		57_b	15_a			
	5	Northwest	30_c									246_a		$34,500_b$	$2,600_b$			10_c	480_a	$6.8E5_f$	$1.1E4_f$
Average Daily Traffic No./day	<	500																	252_b		
		500 - 5,000		$9,500_c$	$83,000_c$			419_b						$18,900_a$	$1,060_c$		17_d				3.4E5d
		5,000 - 15,000																18_a			
	>	15,000	82_d													357_a				$3.8E5_e$	
Type of Landscaping Beyond the Sidewalk	1	Grass													$1,370_b$					$8.3E5_d$	$7.4E4_d$
	2	Trees	43_b																	$1.1E7_b$	
	3	Landscaped buildings	93_b																		
	4	Hard surfaces			$78,000_c$	790_b		461_b										16_a		$7.1E5_c$	
Street Surface Material	1	Asphalt				$2,470_a$				$1,770_b$								18_a			
	2	Concrete	38_b	$72,000_c$		$3,520_b$		$2,600_b$		$6,680_b$					$1,280_c$			45_c			
		All data	156_b	$19,900_b$	$140,000_b$	$1,280_b$	$2,930_c$	804_b	$2,640_c$	$2,950_b$	3.4_a	211_a	104_a	$22,000_a$	$1,810_a$	418_a	35_a	21_a	370_a	$2.5E6_c$	$1.7E5_b$

[a] Only those subset means are shown which differ from the means of the set of all data at the 90-percent confidence level (Student $t \geq 1.80$, Degrees of Freedom ≥ 10). Total number of permitted substitutions = 74. Percent Standard Error of the Mean Subscripting Code: a = 0 - 9, b = 10 - 19, c = 20 - 29, d = 30 - 39, e = 40 - 49, f = 50 - 62.

[b] Coliform counts are expressed in computer notation, i.e., $E5 = 10^5$.

Note: Preliminary decisions to include or exclude values made on the basis of Table C-6. All values included were reaffirmed by checking the original data. In this check, values were excluded if $n < 10$ and the diversity of the sample by the other independent parameters was small, e.g., if all loadings for < 500 ADT came from Baltimore. Climate 6 was rejected because it is redundant to the Grand Mean.

Table 7. EIGHTY PERCENT CONFIDENCE LEVEL[a]

	Category	lbs/curb mi/day	Concentrations in micrograms per gram of dry solid																No./gram	
		Loading	BOD_5	COD	OPO_4	TPO_4	NO_3	NH_4	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TCOLI[b]	FCOLI[b]
Land Use	10 Open space																			
	20 Residential		$14,000_b$	$82,000_b$	850_b		550_c		$1,800_a$			93_a		$1,430_b$		28_b				
	30 Commercial	74_c	$58,700_c$	$269,000_c$	$2,250_c$		$1,580_c$		$6,430_a$			133_b		$3,440_b$		48_b		520_b		
	40 Light industry																			
	50 Heavy industry										278_b		$28,600_b$	$1,160_c$	570_b				$8.2E5_e$	
Climate	1 Northeast	291_c							$5,970_c$	2.6_b	139_b		$17,700_b$	870_c	363_a	31_c	27_b	260_b		$4.4E5_c$
	2 Southeast	103_b	$29,100_b$		$2,240_a$				$1,970_a$			137_b		$1,370_b$		21_b	28_b			$7.0E4_d$
	4 Southwest	50_c			470_b						241_a	78_a		$2,520_b$		57_b	15_a		$5.7E8_d$	
	5 Northwest	30_c									246_a		$34,500_b$	$2,600_b$			10_c	480_a	$6.8E5_f$	$1.1E4_f$
Average Daily Traffic No./day	< 500													$1,210_d$				252_b		$6.9E4_f$
	500 - 5,000		$9,500_c$	$83,000_c$	741_d		419_b						$18,900_a$	$1,060_c$		17_d	34_c			$3.4E5_d$
	5,000 - 15,000																18_a			
	> 15,000	82_d													357_a				$3.8E5_e$	
Type of Landscaping Beyond the Sidewalk	1 Grass		$32,400_c$											$1,370_b$		27_b			$8.3E5_d$	$7.4E4_d$
	2 Trees	43_b																	$1.1E7_b$	
	3 Landscaped buildings	93_b																		$2.5E5_d$
	4 Hard surfaces		$13,700_b$	$78,000_c$	790_b		461_b							$2,370_b$			16_a		$7.1E5_c$	
Street Surface Material	1 Asphalt				$2,470_a$				$1,770_b$								18_a			
	2 Concrete	38_b	$72,000_c$		$3,520_b$		$2,600_b$		$6,680_b$					$1,280_c$		24_c	45_c	292_b		
	All data	156_b	$19,900_b$	$140,000_b$	$1,280_b$	$2,830_c$	804_b	$2,640_c$	$2,850_b$	3.4_a	211_a	104_a	$22,000_a$	$1,810_a$	418_a	35_a	21_a	370_a	$2.5E8_c$	$1.7E5_b$

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[a] Only those subset means are shown which differ from the mean of the set of all data at the 80-percent confidence level (Student t ≥ 1.29, Degrees of Freedom ≥ 10). Total number of permitted substitutions = 103. Percent Standard Error of the Mean Subscripting Code: a = 0 - 9, b = 10 - 19, c = 20 - 29, d = 30 - 39, e = 40 - 49, f = 50 - 62.

[b] Coliform counts are expressed in computer notation, i.e., E5 = 10^5.

all data and enter the appropriate table at the line labeled "All Data."

b. Select a category of land use, climate, average daily traffic, landscaping, or street surface material which best applies to the area of study and move upward to the line of data to the right of that category heading.

c. Substitute those values available in the row selected for the corresponding values in the row entitled "All Data." The resulting row of data may be used in all later steps. Caution: It is not permissible to use more than one row of substitutions at a time, i.e., to use a BOD value for land use and COD for climate to form a new row of loading rate and composition data. Analysis of the data indicates that there is a relationship between loadings by category but that this relationship is not valid when categories are mixed. It is both proper and useful, however, to repeat the above process to obtain several new rows of data to present a range of composition and loading rates.

d. Attach the data from Table 4, if desired.

e. Convert the loading rate to load per acre of street surface as described in the discussion for Level I. Carry the composition data along for subsequent use.

- Level III. This level makes maximum use of the available loading rate and solid composition data. Alternatively, the published available data may be replaced by site specific data available to the user. Recommended procedures for conducting site specific tests are given in Appendix B.

Alternative A

The user has available site specific loading rate and solids composition data. In this case, he may either proceed directly to subsequent material or compare his data with the data presented in this manual to verify the analysis and field sampling procedures. The data for comparison may be obtained by procedures described in Level II of this section.

Alternative B

In this alternative, it is assumed that the user lacks site specific data and wishes to examine the available published data for source and reliability.

It is recommended that the planner turn to Appendix A which contains a narrative description of the sources of data, the procedures for processing the data, the procedures for grouping the available data by categories for detailed analysis, the calculation of the statistical parameters which describe the data and using those parameters to select the data most applicable to the specific site.

3.3 Storm Event Characteristics and Impervious Runoff Rate

3.3.1 Method of Computing Runoff Rate From Impervious Surfaces

The determination of a specific runoff rate for an assessment of urban runoff requires a knowledge of rainfall/runoff relationships, including the rate of runoff which results from a storm of a specified intensity. The method of runoff coefficient can be used to approximate the rate of runoff resulting from a storm event. This technique provides the average rate of runoff from a storm, although it does not depict the variability of runoff rate during the storm.

The method of runoff coefficient assumes that the rate of runoff is a percentage of the rate of precipitation. If this is true, then:

$$R = kP$$

where R = runoff rate in inches per hour

P = precipitation in inches per hour

k = runoff coefficient (a dimensionless constant varying from 0 to 1.0)

Values of the runoff coefficient, k, for impervious surfaces are given in Table 8. These values of k can be used directly in conjunction with the above equation when predicting the runoff rate from an impervious surface. An example of the runoff coefficient method is given in Example 3 of Section II.

Table 8. VALUES OF RUNOFF COEFFICIENT, k

Impervious Surfaces	Approx. k
Flat (<2% slope)	0.80
Moderate (2 to 7% slope)	0.85
Steep (>7% slope)	0.90

3.3.2 Selection of Storm Event

Theoretically, any storm event (and its resultant runoff) can be selected for an assessment of urban runoff. A particular storm event can be characterized by its duration, its average intensity, and its frequency of occurrence.

The implications of selecting a specific storm event are two-fold; the selected storm event will (1) generate a certain volume of runoff and (2) remove a certain percentage of available street surface contaminants.

The characteristics of the selected storm event (i.e., its duration, average intensity, and frequency of occurrence) will greatly influence the results of one's assessment. Therefore, the following material is presented as general guidance for selecting a storm event.

- Basic Considerations. The pollution potential of urban runoff is influenced by both its quantity and quality. In certain situations, a large volume of moderately polluted runoff may contribute a greater pollutant load to a receiving water than a smaller volume of highly polluted runoff even though the pollutant concentration is considerably greater within the smaller volume. Consequently, this raises the question as to which is more significant with regard to receiving waters; pollutant concentration or pollutant load?

Generally, the assimilative characteristics of a receiving water will determine which is more significant. Certain receiving waters are more capable of assimilating a large volume of moderately polluted runoff while others are more capable of assimilating a small volume of highly polluted water.

The percentages of contaminants removed from street surfaces by various combinations of runoff rate and runoff duration are given in Table 9. Examination of the values within the table reveals that contaminant removal is a direct function of the total inches of runoff. Consequently, a runoff rate of 0.5 inches per hour which lasts for 1 hour will remove the same percentage of contaminants as a runoff rate of 1.0 inches per hour which lasts for 0.5 hours since, in both cases, 0.5 inches of total runoff occurs.

Figure 2 describes street surface contaminant removal as a function of total inches of runoff. The shape of the curve indicates that, as contaminant removal increases, the total inches of runoff increases exponentially. Therefore, Figure 2 reveals that contaminants become increasingly more difficult to remove (i.e., require increasingly more

Table 9. PERCENT OF CONTAMINANTS REMOVED FROM STREET SURFACES BY RUNOFF RATE/DURATION

Runoff Rate (in./hr)	Runoff Duration (hr)							
	0.25	0.5	1.0	2.0	3.0	4.0	5.0	6.0
0.1	10.9	20.5	36.9	60.1	74.8	84.1	90.0	>90.0
0.2	20.5	36.9	60.1	84.1	>90.0	>90.0	>90.0	
0.3	29.1	49.8	74.8	>90.0				
0.4	36.9	60.1	84.1					
0.5	43.7	68.3	90.0					
0.6	49.8	74.8	>90.0					
0.7	55.3	80.0						
0.8	60.1	84.1						
0.9	64.5	87.4						
1.0	68.3	90.0						

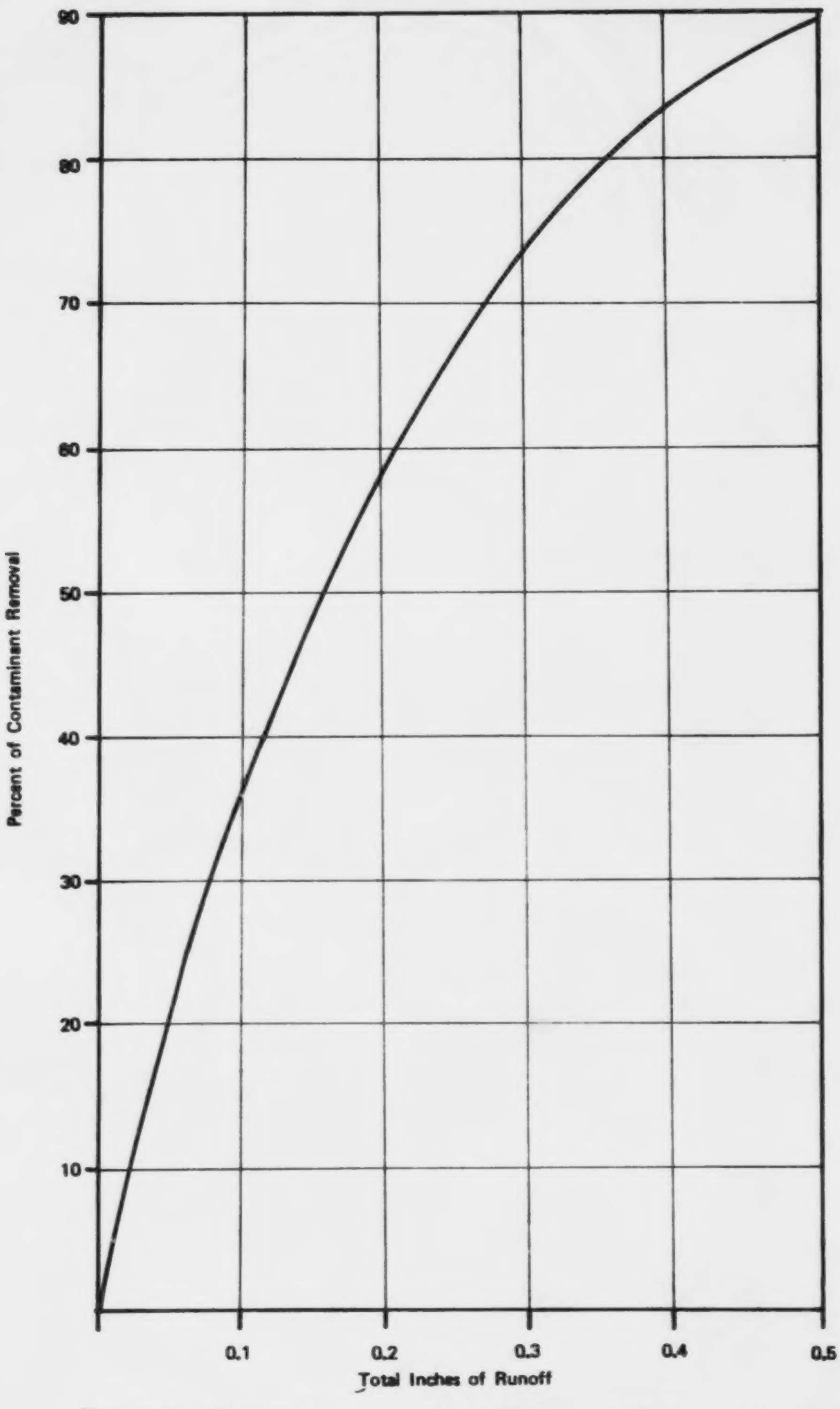


Figure 2. Street Surface Contaminant Removal as a Function of Runoff

runoff) within the higher percentage ranges of contaminant removal. Consequently, as the total inches of runoff increase, the total pollutant load removed will increase while the average pollutant concentration will decrease due to dilution from the additional increments of runoff required to remove contaminants within the higher percentage ranges.

Figure 3 describes average pollutant concentration as a function of street surface runoff and contaminant removal. This curve confirms that average pollutant concentration decreases as the total inches of runoff increase.

Therefore, a storm event which produces a large volume of runoff will contribute a greater pollutant load to a receiving water than a storm event which produces a smaller volume of runoff. However, runoff from the latter will contain a greater average pollutant concentration. It is strongly recommended that the user keep the above phenomenon in mind while selecting a storm event for assessment.

- Basic Procedure. It is recommended that the user select a "typical" storm event which has a duration of 30 minutes and would likely occur several times a year in the geographical vicinity of the study area. A storm with an occurrence frequency of six months or less would be appropriate (often a local weather bureau can provide this kind of information).

If local sources of information cannot provide statistical storm frequency data, it is recommended that the user select a one-year storm with a duration of 30 minutes, using the frequency curve given in Figure 4.

The general procedure for selecting a storm event is as follows:

(1) Select a "typical" storm event which has a duration of 30 minutes and would likely occur several times a year in the geographical vicinity of the study area. If such a storm event is indeterminable, select a 1-year

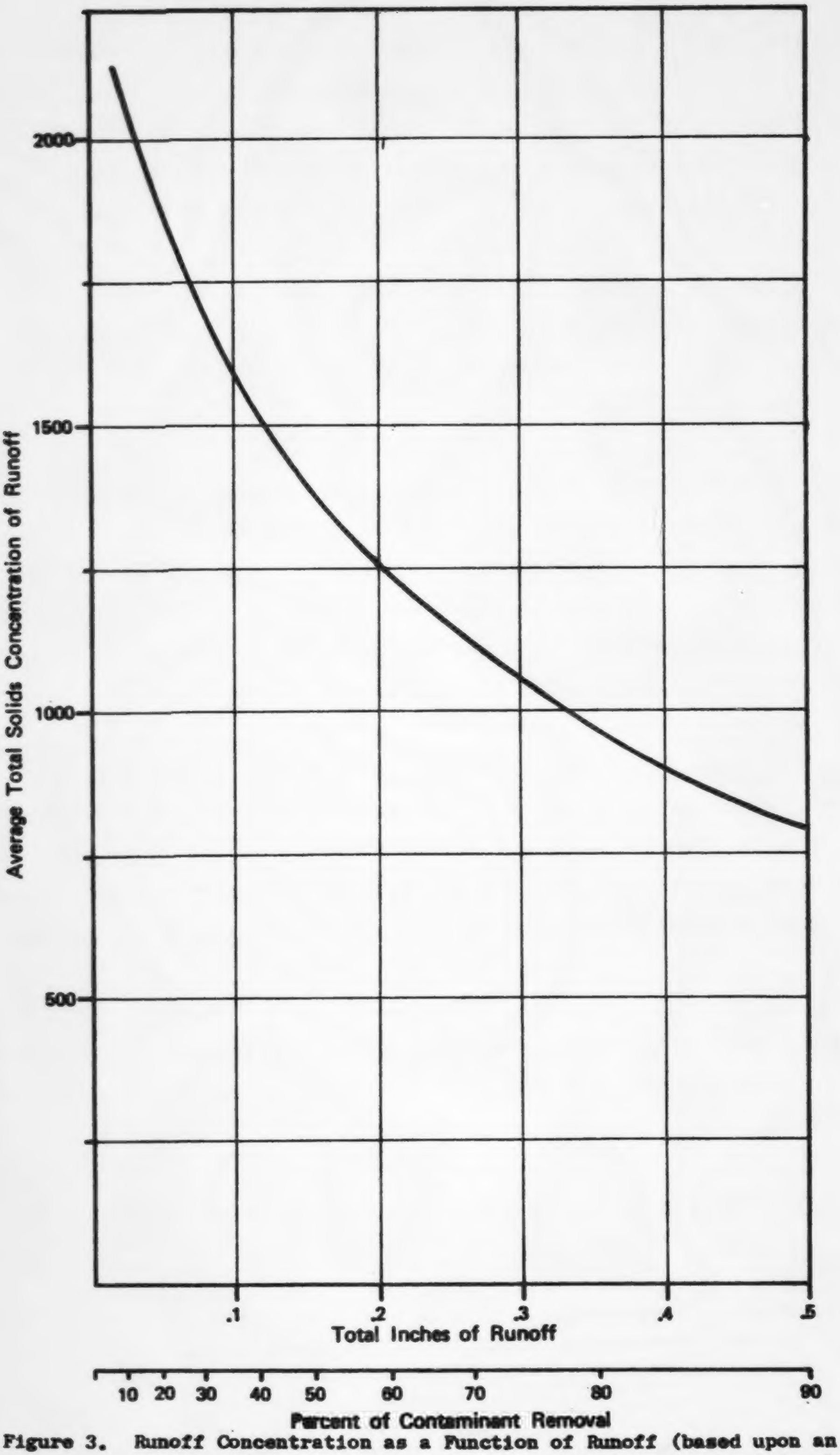


Figure 3. Runoff Concentration as a Function of Runoff (based upon an initial contaminant loading of 100 lbs/acre of street surface)

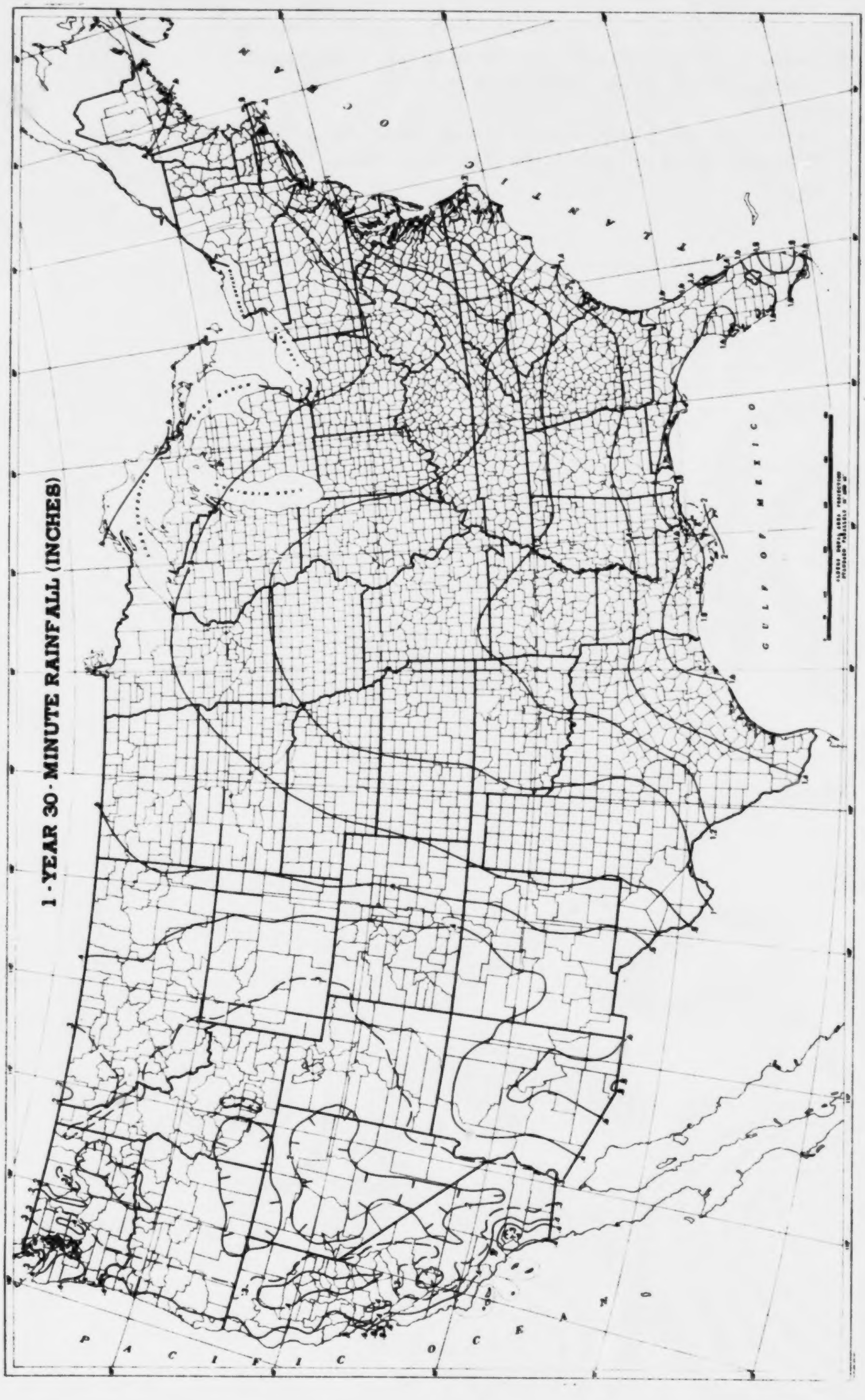

1-YEAR 30-MINUTE RAINFALL (INCHES)
ATLANTIC OCEAN
GULF OF MEXICO
PACIFIC OCEAN

Figure 4. 1-Year 30-Minute Rainfall (Inches) storm with a duration of 30 minutes from the frequency curve given in Figure 4.

(2) Using the method of runoff coefficient, determine the runoff rate resulting from the selected storm event.

Example 5 demonstrates the selection of a storm event.

4.0 DETERMINATION OF QUANTITY AND FLOW OF RUNOFF

4.1 General Assumptions and Background

As stated previously, the procedures presented in Section I are intended to yield a general, first glance assessment of the water quality aspects of urban runoff. In light of this manual's intended degree of accuracy, the authors have chosen to ignore runoff contributed by pervious surfaces.

Therefore, it is assumed that no significant amount of runoff will originate from pervious surfaces during a storm event of short duration (i.e., a storm of 30 minutes duration). Moreover, it is assumed that the amount of rainfall during a storm event of short duration will not exceed the infiltration capacity and surface retention capacity of pervious surfaces and, consequently, the pervious runoff that will occur is minimal in comparison to impervious runoff.

A short duration, high intensity storm will result in greater quantities of runoff from pervious areas; however, the quantity of runoff will cause the pollutant concentrations to be diluted so that it would effectively be less of a problem than using the above assumptions.

Since street surfaces have been shown to be the primary source of pollutants associated with urban stormwater runoff, pervious runoff will essentially dilute street surface runoff, whereby slightly polluted pervious runoff mixes with highly polluted street surface runoff. Since pervious runoff will be ignored, the manual's assessment of urban runoff becomes somewhat of a "worst case" assessment.

By dealing with a storm event of short duration, it has been demonstrated that pervious runoff can be ignored without serious consequences. However, interconnected impervious areas other than street surfaces (i.e., driveways, parking lots, etc., which are ultimately connected to a street surface via other impervious surfaces) cannot be ignored. These non-street interconnected impervious areas will contribute a significant amount of runoff, even during storms of short duration. However, since contaminant loadings are provided only for street surfaces and, moreover, since street surfaces have been shown to be the primary pollutant contributor, the assessment of urban runoff developed in this manual will consider runoff from non-street impervious area as being unpolluted and merely acting as dilution water.

For a more accurate assessment of pollutant concentrations, samples of runoff from non-street impervious areas can be obtained and analyzed. Samples should be taken from a point where runoff flows into the street, as early in the storm event as possible after runoff begins to flow. The impervious area could then be considered as a street surface and the pollutant load determined from the samples converted from an aerial basis to curb mile basis (Table 2).

4.2 Determination of Volume of Runoff

An approximate assessment of urban runoff pollution requires a knowledge of (1) the volume of runoff from impervious surfaces within a selected study area during a given storm event, and (2) the amount of street surface contaminants removed by runoff. Accordingly, the total volume of impervious runoff from a study area may be estimated by the following equation:

$$\text{Volume of Runoff (cf)}^* = \left[\text{Runoff Rate (in./hr)}\right] \times \left[\text{Interconnected Impervious Area (acres)}\right] \times \left[1{,}815\right]$$

---

* Equation is applicable for a 30-minute runoff duration.

4.3 Definition of a Hydrograph and a Unit Hydrograph

A thorough assessment of urban runoff pollution requires more than just an estimate of the impervious runoff volume from a study area. Since the removal of street surface contaminants varies according to the rate of street surface runoff, a method which describes impervious runoff as a function of time is required for a thorough analysis.

The concept of a hydrograph can be used to describe runoff resulting from a rain event. A hydrograph portrays the rate of runoff as a function of time. The runoff rate corresponds to a flow rate measured at a designated inlet located within a particular study area. A sample study area and its corresponding hydrograph are shown in Figure 5.

A hydrograph describes the rate of runoff from a study area during a specific storm event. Unfortunately, an individual hydrograph is not directly applicable to storm events with different intensities and/or durations.

To portray the runoff characteristics of a given urban watershed for storms of varying intensities with a single hydrograph requires a normalization method to describe the general runoff characteristics of the given watershed. The normalization method employed is that of the unit hydrograph.

A unit hydrograph is defined as "the hydrograph of direct runoff resulting from one inch of effective rainfall (rainfall which causes runoff) generated uniformly over the basin area at a uniform rate during a specified period of time or duration."[1]

The concept of a unit hydrograph assumes that (1) the effective rainfall occurs at a uniform rate, and (2) the effective rainfall is uniformly distributed over the watershed with respect to time and area.

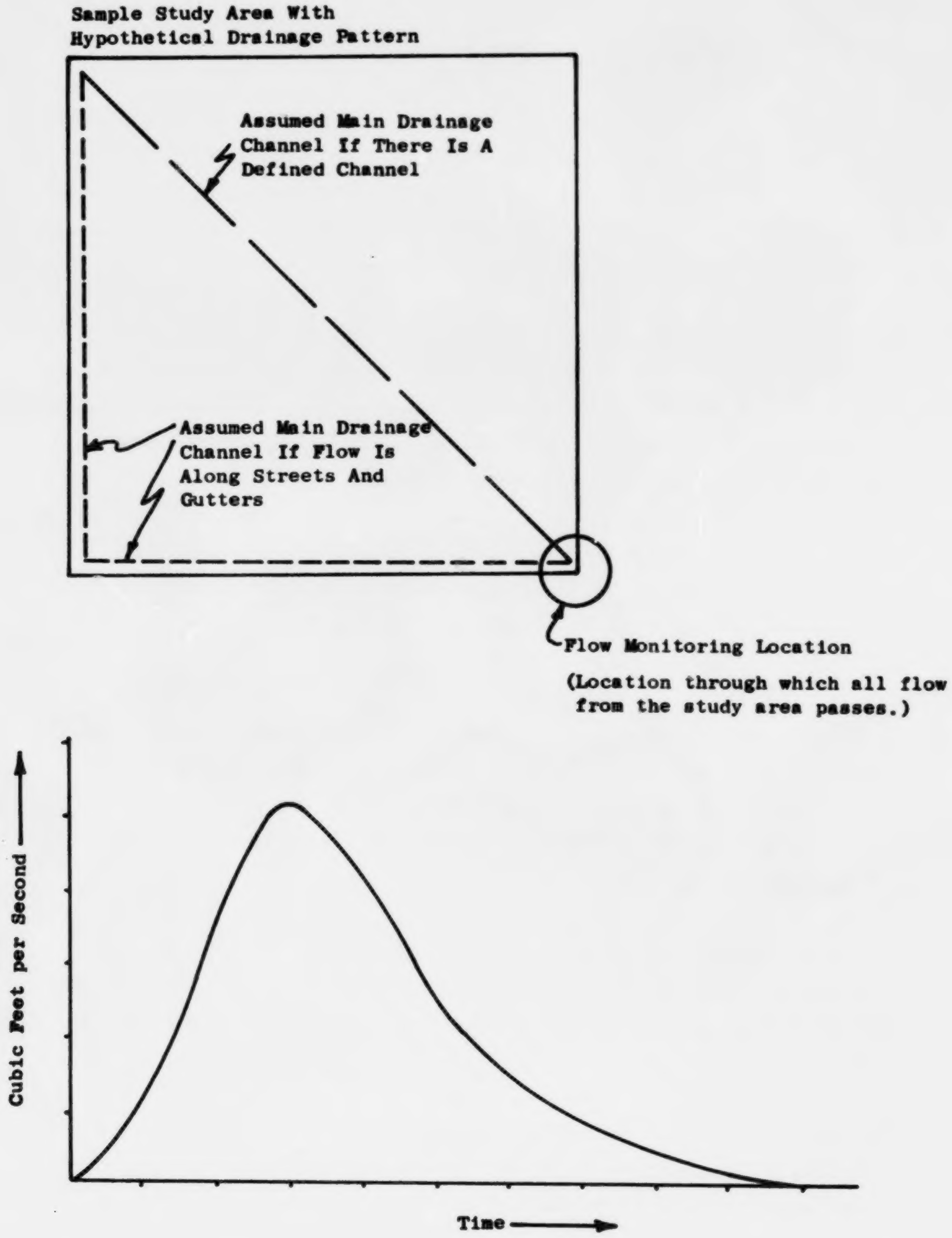

Sample Study Area With
Hypothetical Drainage Pattern
Assumed Main Drainage Channel If There Is A Defined Channel
Assumed Main Drainage Channel If Flow Is Along Streets And Gutters
Flow Monitoring Location
(Location through which all flow from the study area passes.)
Cubic Feet per Second
Time

Figure 5. Sample Study Area and Corresponding Hydrograph

4.4 Development of Unit Hydrograph for Entire Study Area

The following procedure provides a means of developing a unit hydrograph which portrays all runoff, impervious and pervious, from a study area. This procedure will subsequently be modified in such a manner as to ignore pervious runoff.

A method of synthesizing unit hydrographs for an entire study area is given in a study by Espey[2] who collected data from 11 urban watersheds in Houston and 22 urban watersheds in different geographical locations within the United States. Multiple linear regression analysis was used to develop general equations which describe the 30-minute unit hydrograph for urban conditions.

The problem of using statistics to synthesize a unit hydrograph is by definition one of approximating the hydrograph shape. The approach used by Espey was to describe the hydrograph in terms of typical hydrograph dimensions instead of attempting to derive an actual mathematical function for the hydrograph.

To describe the hydrograph, the following parameters were chosen:

(1) T_R, the time of rise, defined as the time, in minutes, from the beginning of surface runoff/to the peak runoff.

(2) Q, the peak discharge, defined as the peak value of discharge, in cfs.

(3) T_B, the base time, defined as the time, in minutes, from the beginning to the end of surface runoff,

(4) W_{50}, the time, in minutes, between the points on the hydrograph when the discharge represented by Q_{50} is half the peak discharge.

(5) W_{75}, the time, in minutes, between the points on the hydrograph when the discharge represented by Q_{75} is three-fourths of the peak discharge.

A summary of these parameters is shown on a typical hydrograph in Figure 6. The statistical work by Espey produced the following equations which represent the 30-minute unit hydrograph for an urban watershed:

$$T_R = 13.12\ L^{0.315}\ S^{-0.0488} I^{-0.490}$$

$$Q = 3.54 \times 10^4\ T_R^{-1.10}\ (A/640)$$

$$T_B = 3.67 \times 10^5\ (A/640)^{1.14} Q^{-1.15}$$

$$W_{50} = 4.14 \times 10^4\ (A/640)^{1.03} Q^{-1.04}$$

$$W_{75} = 1.34 \times 10^4\ (A/640)^{0.92} Q^{-0.94}$$

where A is the size of the study area or subarea in acres,

L is the length of the main drainage channel in feet, *

S is the slope of the main drainage channel in feet/feet,

I is the percent of impervious cover for the study area or subarea.

Espey's equations can be solved directly or with the assistance of Figure 7, which is used in conjunction with Figures 8 through 11. Figure 7 is first used to estimate a value of Q/A. In turn, the estimated value of Q/A is used in Figures 8 through 11 to predict values of T_R, T_B, W_{50}, and W_{75}, respectively.

---

* If actual value of main drainage channel is available, it should be used in place of approximation shown in Figure 5. If drainage mainly takes place along street gutters in the absence of a well-defined channel, then L should be taken to be equal to the sum of two sides of the rectangular urban area shown in Figure 5.

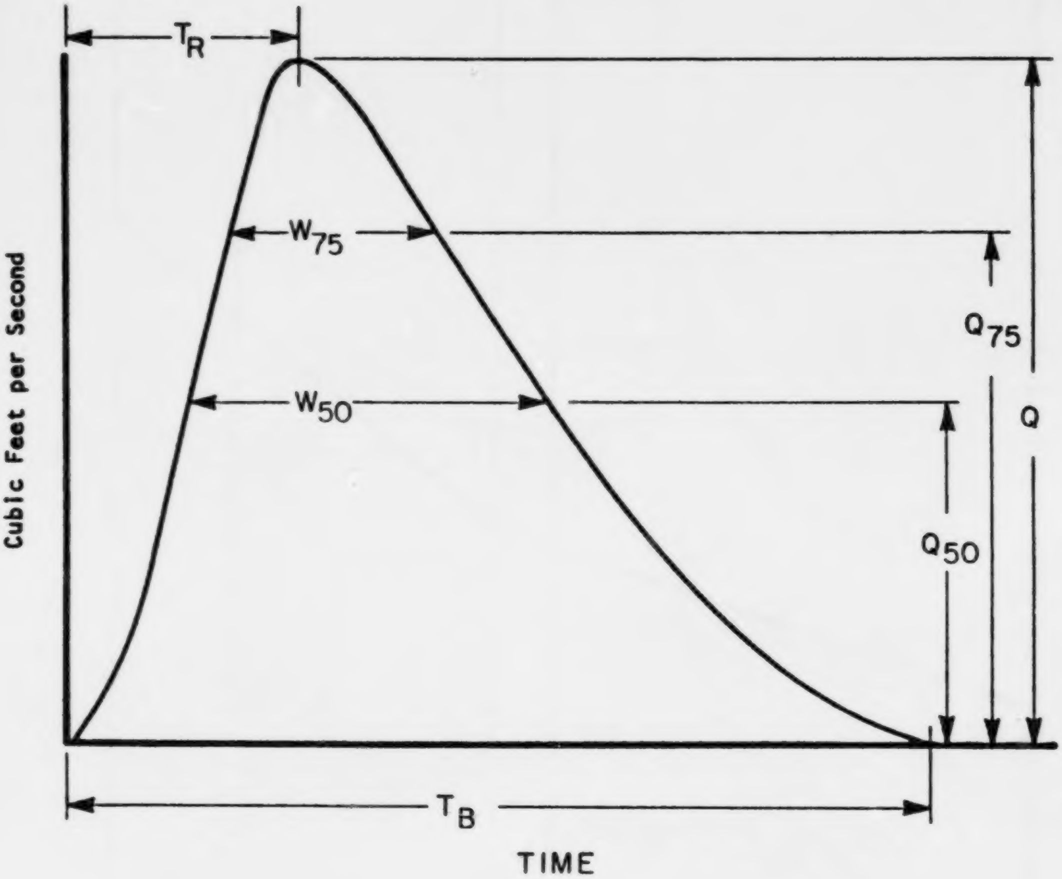

T_R
W_75
W_50
Q_75
Q
Q_50
Cubic Feet per Second
T_B
TIME

Figure 6. Definition of Unit Hydrograph Properties

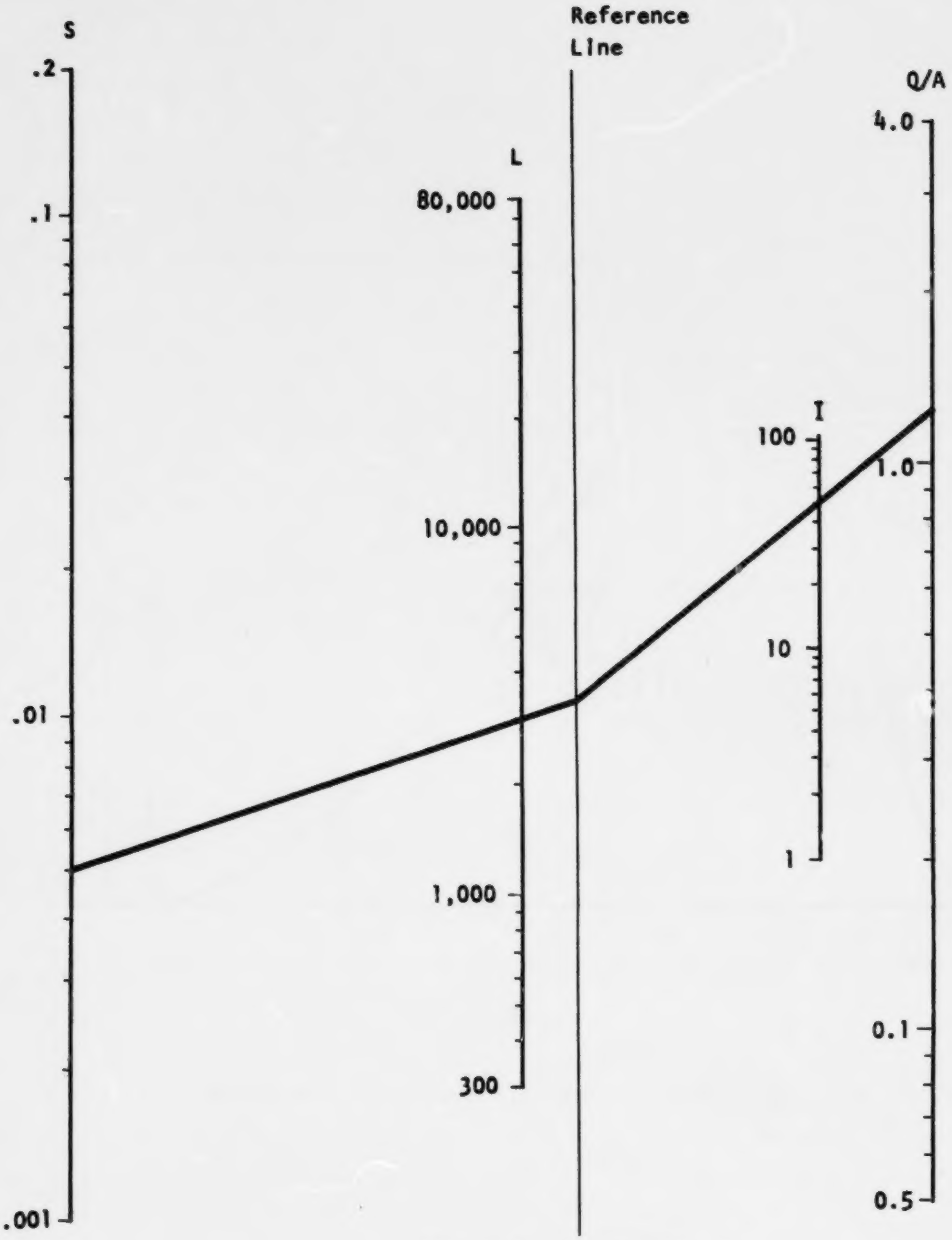


Figure 7. Nomograph

Example: Slope = 0.005
Length of Main Drainage Path = 3,000 ft
Imperviousness = 50%
Therefore $\frac{Q}{A} = 1.2$

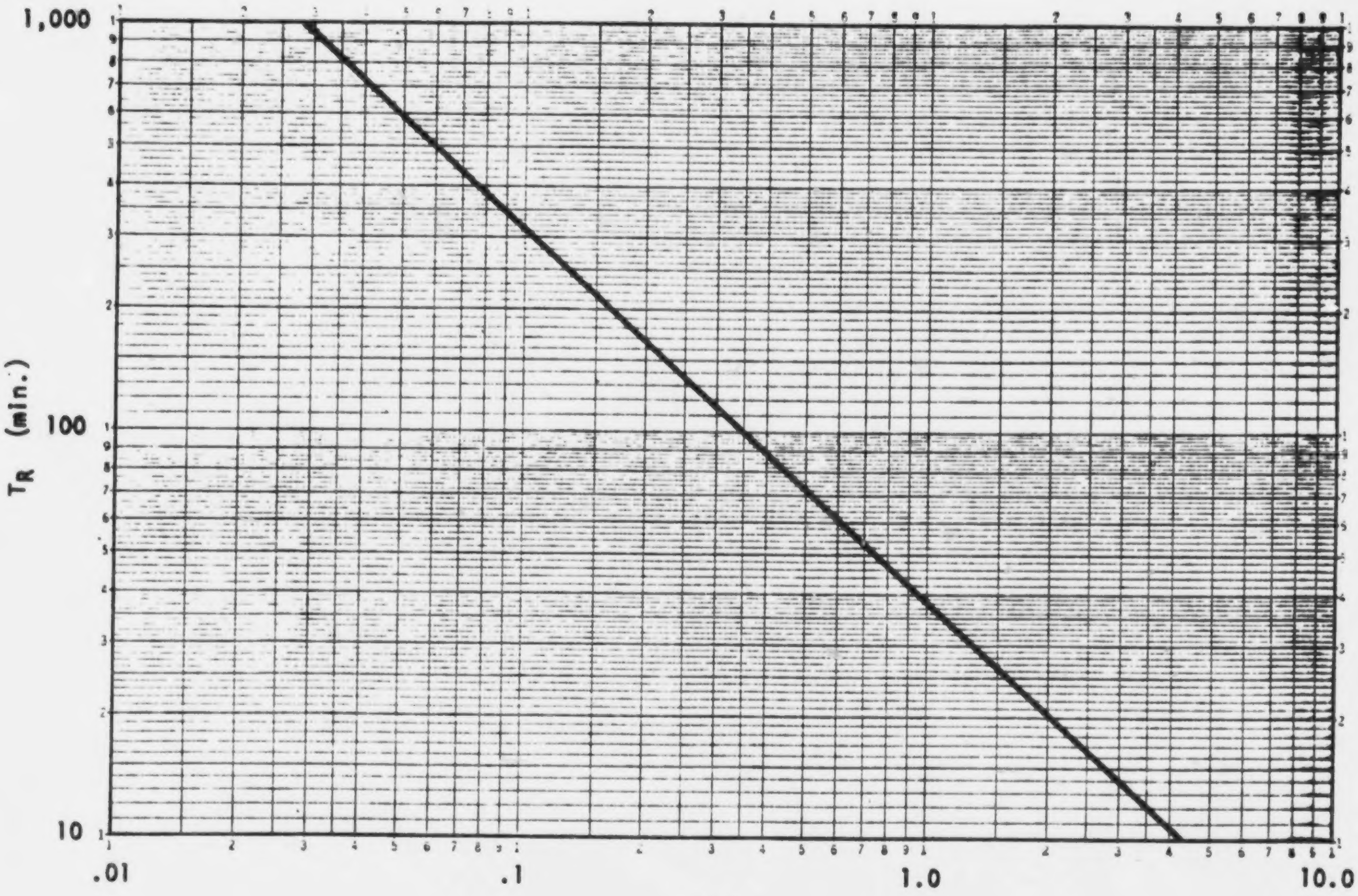


Figure 8. Determination of T_R

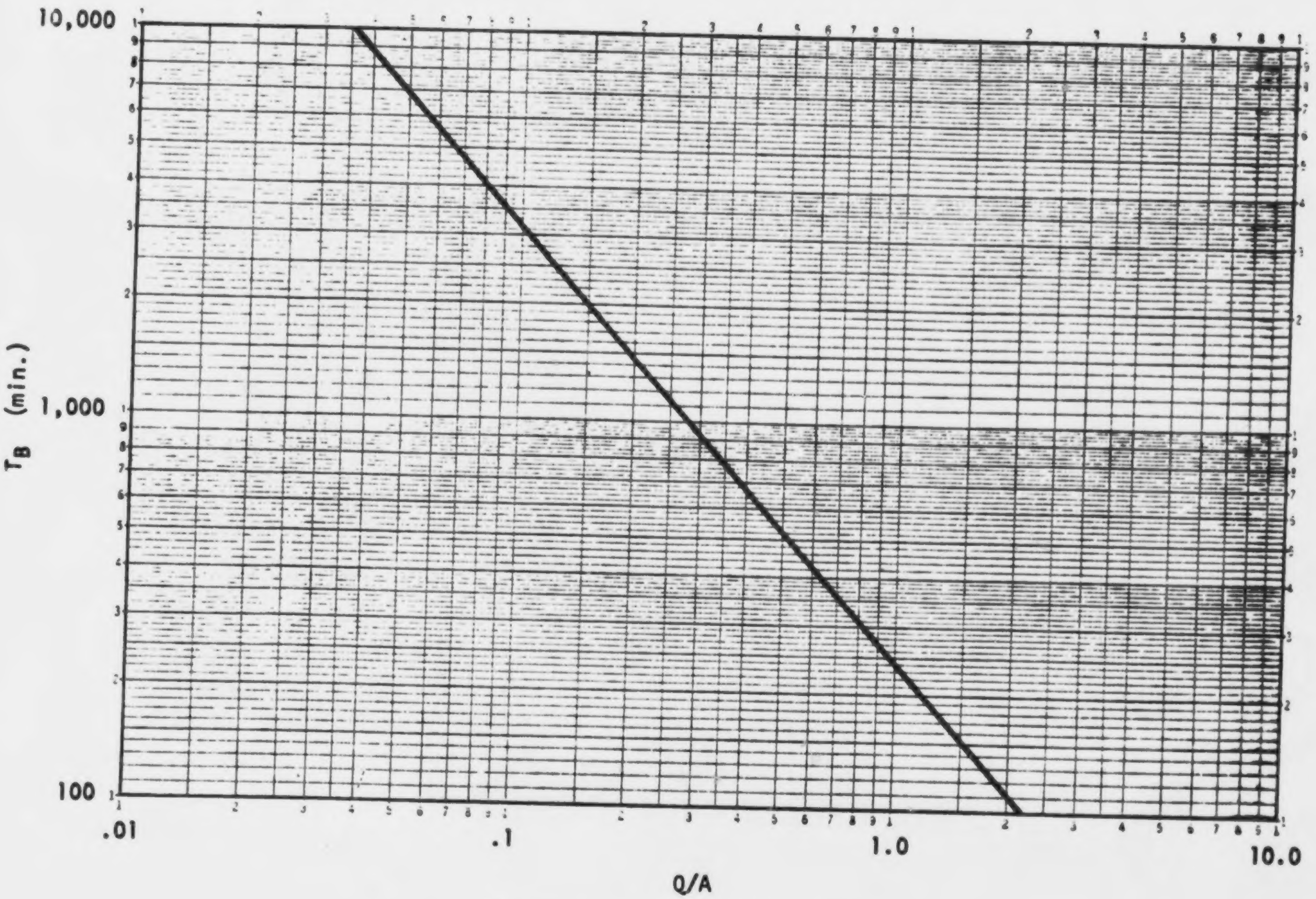


Figure 9. Determination of T_B

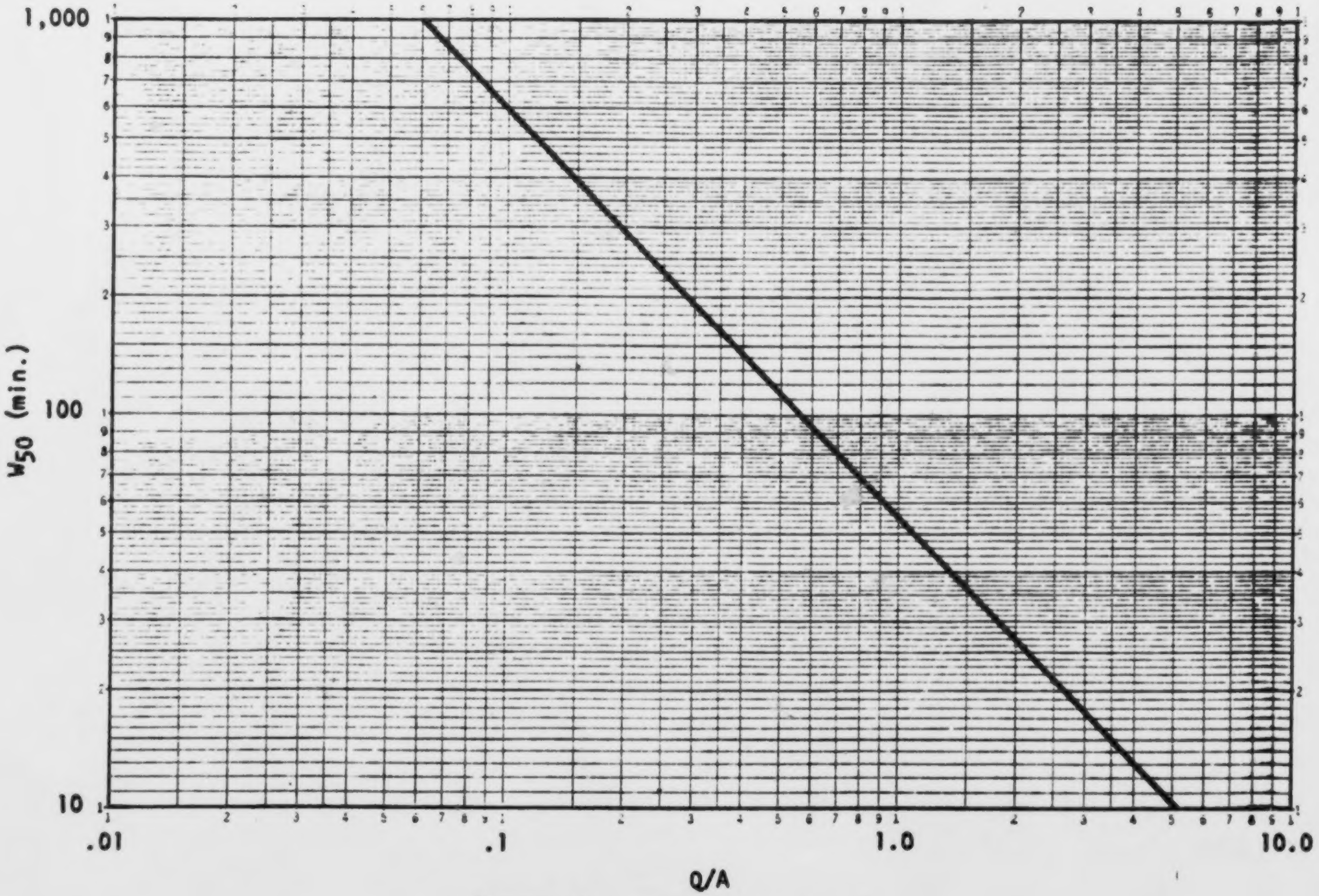


Figure 10. Determination of W_{50}

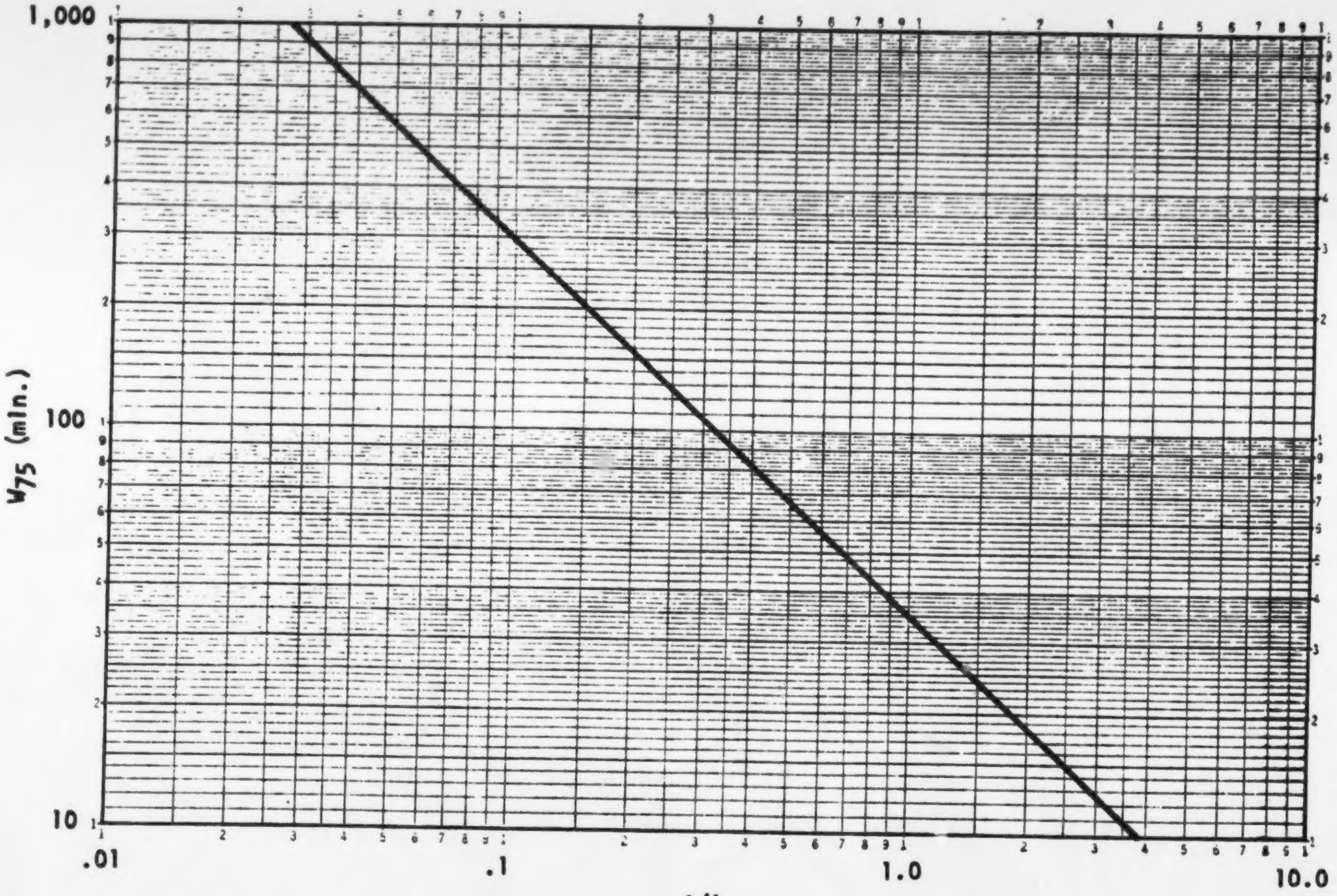


Figure 11. Determination of W_{75}

The characteristics of the urban watersheds upon which Espey based his equations were within the following range of data:

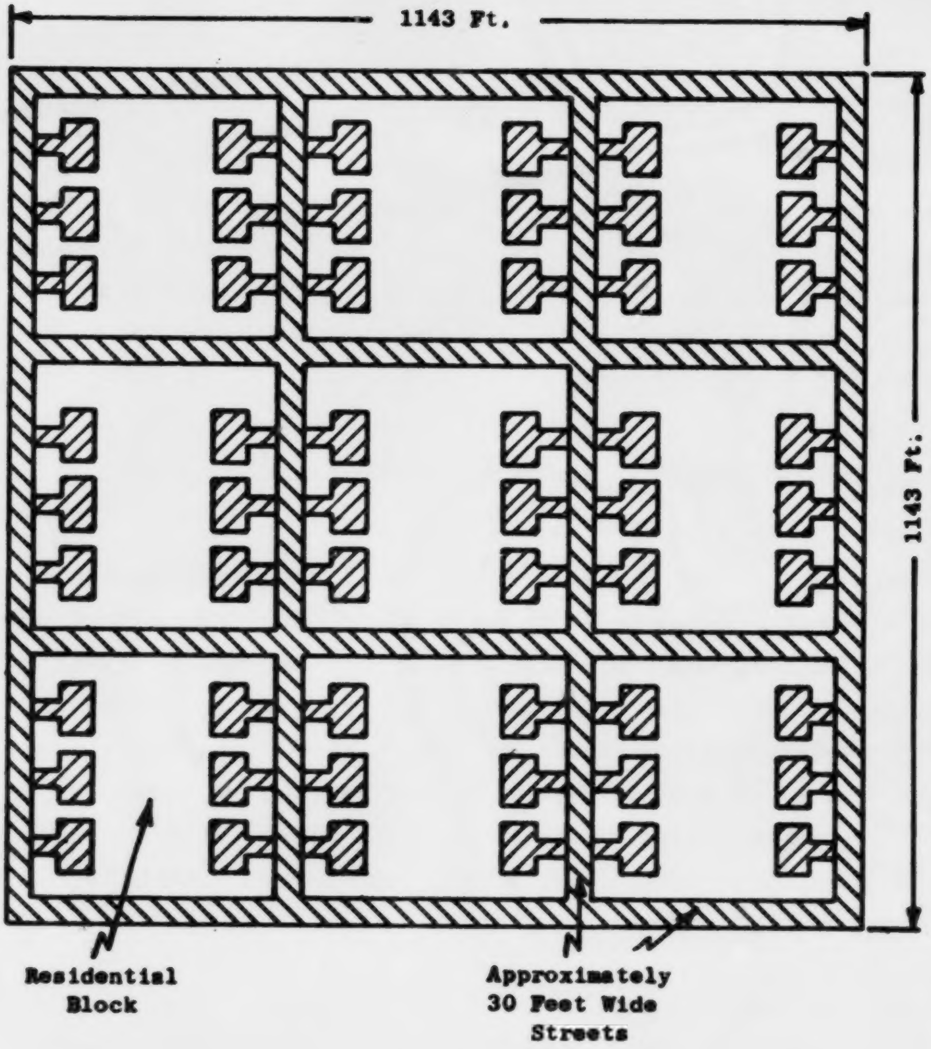
Area of Watershed:	8.2 to 59,000 acres
Length of Main Drainage Channel:	560 to 123,000 feet
Slope of Main Drainage Channel:	.00047 to .146 feet/feet

Using the equations derived by Espey, one may synthesize a unit hydrograph to describe an entire study area. Although the required calculations are reasonably simple, a certain degree of subjectivity will be involved in actually drawing the shape of a unit hydrograph in terms of the graphical variables (T_R, Q, T_B, W_{50}, W_{75}). An example of unit hydrograph synthesis using Espey's equations is given in Example 6 of Section II.

4.5 Development of Unit Hydrographs for Impervious Area and Street Surfaces

As presented in the previous section, Espey's equations enable one to develop a unit hydrograph for an entire study area, comprised of runoff originating from both impervious and pervious surfaces. However, subsequent procedures require the development of two other unit hydrographs; one which describes runoff from interconnected impervious surfaces and another which describes runoff originating from street surfaces within the study area. Consequently, the authors of this manual have taken the liberty of adapting Espey's equations to satisfy the needs of the manual as follows.

Figure 12a shows a typical urban study area comprised of about 15 acres of pervious surface and 15 acres of impervious surface, of which about 10 acres are streets. Using Espey's equations, one can normally develop a unit hydrograph for the entire study area and subsequently modify it to reflect a specific runoff rate.


1143 Ft.
1143 Ft.
Residential Block
Approximately 30 Feet Wide Streets

Total Area = 30 Acres

Total Impervious Area = 15 Acres

▧ Street Area = 10 Acres

▨ Off-street Impervious Area (Roofs, Driveways, Etc.) = 15 Acres

Figure 12a. Typical Urban Area

It is assumed that the network of interconnected impervious surfaces can be isolated from the study area and treated as a separate, although irregular, watershed as shown in Figure 12b. Furthermore, it is assumed that, likewise, the street surface network can be isolated from the study area and treated as a separate watershed as shown in Figure 12c.

Using Espey's equations, one can develop a unit hydrograph for the watershed shown in Figure 12b by assuming that the area of the watershed is equal to the area of impervious surfaces (i.e., 15 acres) and that the watershed has an imperviousness of 100 percent. The length and slope of the main drainage channel are considered to be identical to those of Figure 12a. This same approach can be applied toward the development of a unit hydrograph for the watershed shown in Figure 12c, whereby it is assumed that the area of the watershed is equal to the area of street surfaces (i.e., 10 acres) and that the watershed has an imperviousness of 100 percent.

At first glance, the above adaptation of Espey's equations may appear to be a rather severe extrapolation of Espey's work. However, favorable results can be obtained by using this approach. Figure 13 shows unit hydrographs for the study area, impervious surface, street surface and pervious surface runoffs. All of these, with the exception of the pervious surface unit hydrograph, were developed by using Espey's equations in the manner previously described. The pervious surface unit hydrograph was developed by graphically subtracting the ordinates of the impervious surface unit hydrograph from the ordinates of the study area hydrograph.

A visual comparison of the unit hydrographs of Figure 13 indicates that the unit hydrographs behave as expected. Both the impervious surface unit hydrograph and the street surface unit hydrograph reach their peak flow quicker and have shorter time bases than the study area unit hydrograph. Furthermore, pervious runoff does not commence until about

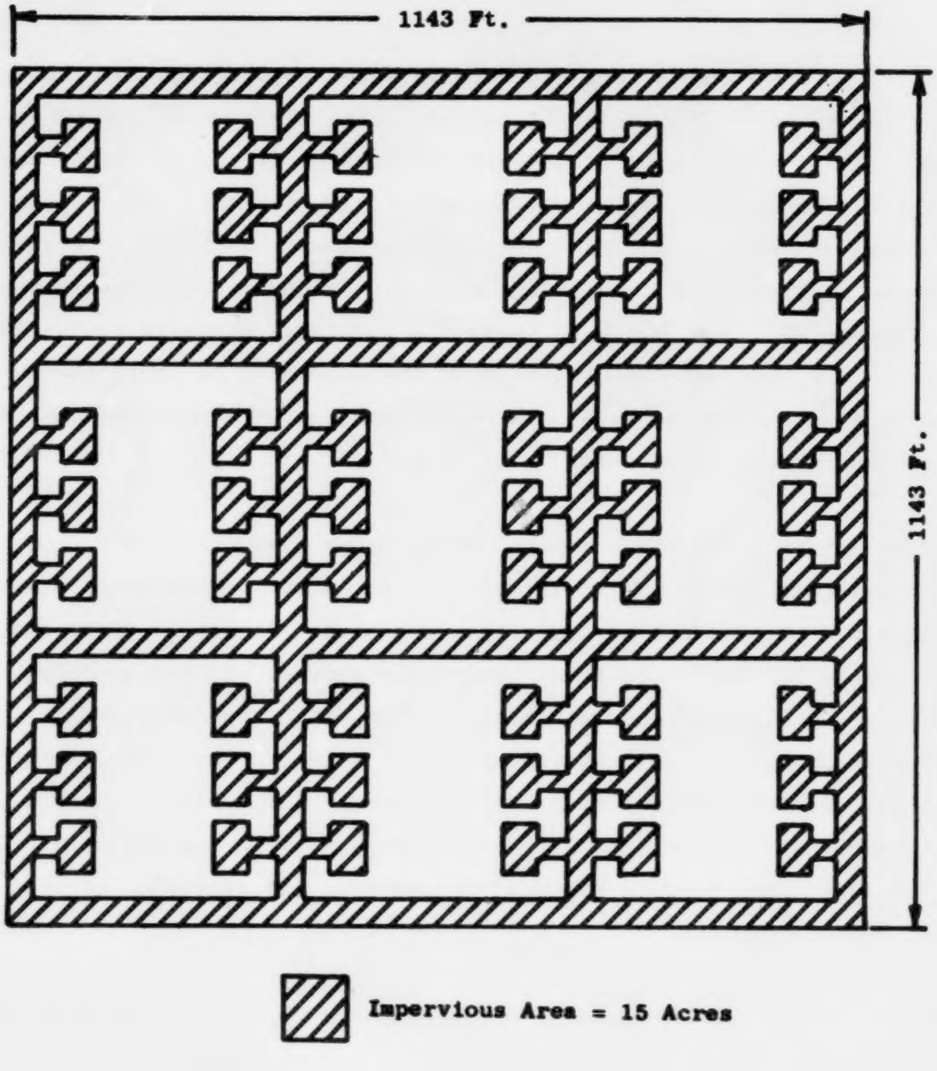

1143 Ft.
1143 Ft.
Impervious Area = 15 Acres

Figure 12b. Impervious Network

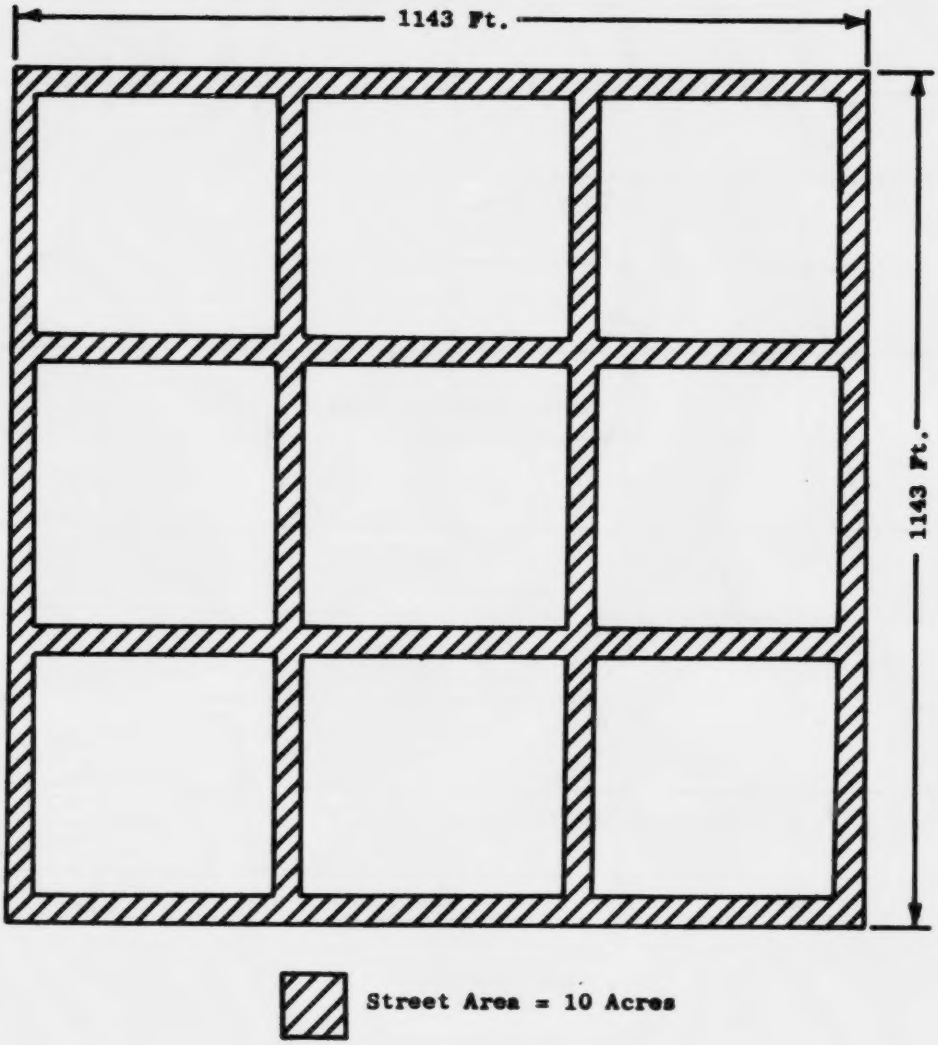

1143 Ft.
1143 Ft.
Street Area = 10 Acres

Figure 12c. Street Surface Network

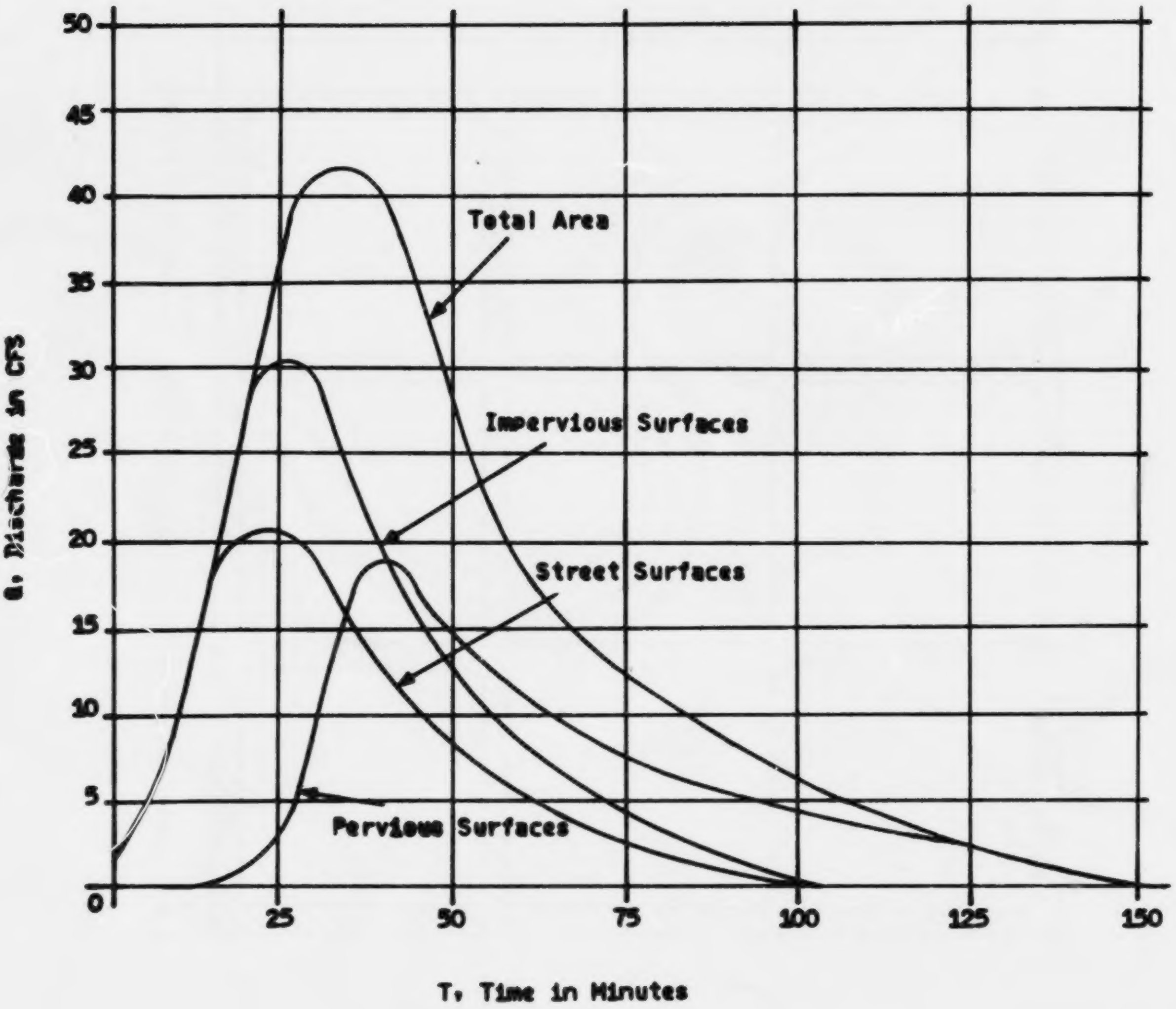


Figure 13. Hypothetical Hydrographs for Urban Watersheds

20 minutes after impervious runoff begins. Generally, it is believed that the adaptation of Espey's equations for the development of impervious surface and street surface unit hydrographs yields adequate results, in light of the manual's intended degree of accuracy.

4.6 Modification of Unit Hydrographs to Reflect Specific Runoff Rate

As previously indicated, a unit hydrograph represents the direct runoff resulting from 1 inch of effective rainfall (rainfall which causes runoff), generated uniformly over an area at a uniform rate during a period of 30 minutes. Once a unit hydrograph has been derived for an area, the unit hydrograph can be modified to reflect a specific runoff rate for the area under consideration, whether it be an entire study area, the impervious area within a study area, or the street surface area within a study area. This modification of the unit hydrograph reduces its value as an indicator of the watershed hydrologic characteristics but is is justified within the limits of accuracy of the procedure as a whole.

The modification of a unit hydrograph to reflect a specific runoff rate is a simple graphical procedure. Since a unit hydrograph represents 1 inch of runoff during an interval of 30 minutes, the implied rate of runoff is 2 inches per hour. Accordingly, modification of the runoff rate is accomplished by multiplying the ordinates of a unit hydrograph by the ratio of: Specific Runoff Rate/2 inches per hour.

For example, in order to modify a unit hydrograph to reflect a runoff rate of 1 inch per hour, multiply the ordinates of the unit hydrograph by the ratio of 1 inch per hour/2 inches per hour = 1/2. This is shown graphically in Figure 14.

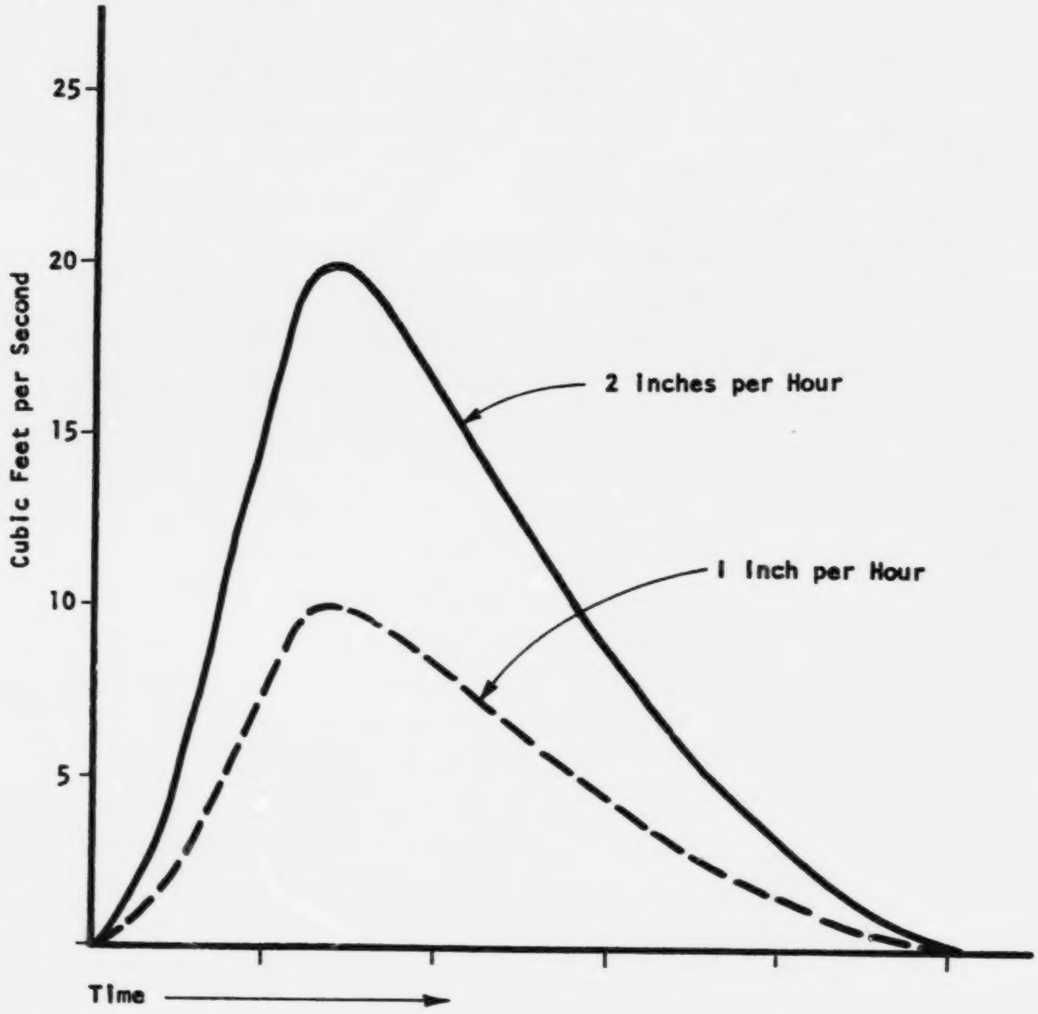


Figure 14. Modification of Unit Hydrograph to Reflect a Specific Runoff Rate

Both an impervious area unit hydrograph and a street surface unit hydrograph can be modified to reflect the impervious runoff rate. This modification leads to the development of an actual hydrograph portraying impervious runoff and another portraying street surface runoff during a specific storm event. The actual hydrographs will be used in subsequent procedures.

5.0 QUALITY OF RUNOFF

In addition to representing the flow of runoff as a function of time, there is a definite need to express the quality of runoff as a function of time. Appropriate graphical representations were felt to be a "pollutograph" (shown in Figure 15a) and a "loadograph" (shown in Figure 15b). A pollutograph portrays pollutant concentration as a function of time while a loadograph portrays pollutant load as a function of time.

The procedure to be utilized in developing pollutographs and loadographs is based upon studies conducted by Metcalf & Eddy[3] and URS Research Company.[4] Both of these studies assumed that the amount of pollutants washed off a street surface, dP, in any time interval, dt, is proportional to the amount of pollutants remaining on the street surface, P:

$$\frac{-dP}{dt} = KP$$

which integrates to

$$P_o - P = P_o (1 - e^{-kt})$$

where P_o = initial loading in pounds
P = pounds remaining after time, t
k = constant
t = time
$P_o - P$ = pounds washed away in time, t

The constant, k, is a function of runoff. To determine k, it was assumed that a uniform runoff of 0.5 inch per hour will wash off 90 percent of the initial pollutant load in one hour (this assumption was verified in the URS study). This leads to the equation:

$$P_o - P = P_o (1 - e^{-4.6\ rt})$$

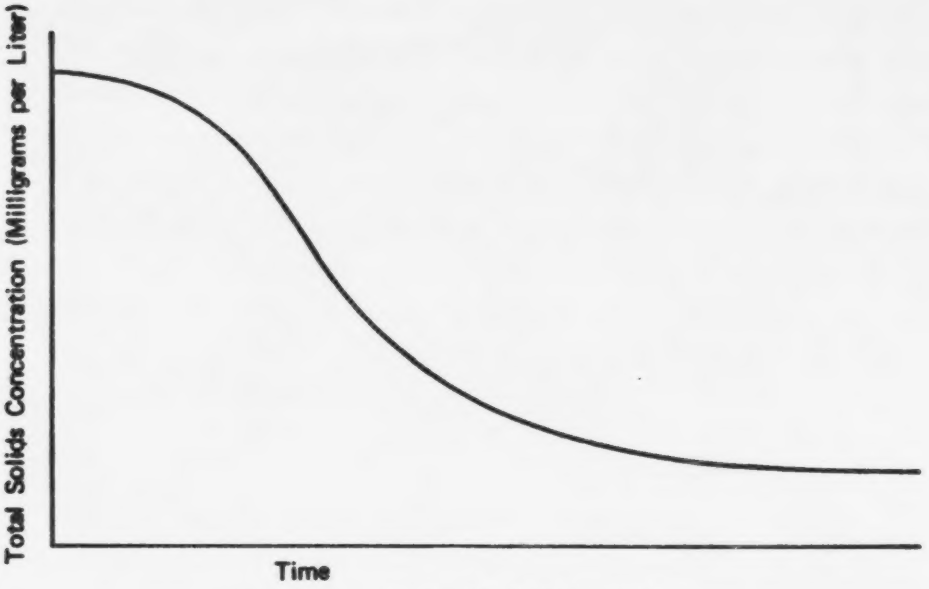


Figure 15a. A Sample Pollutograph

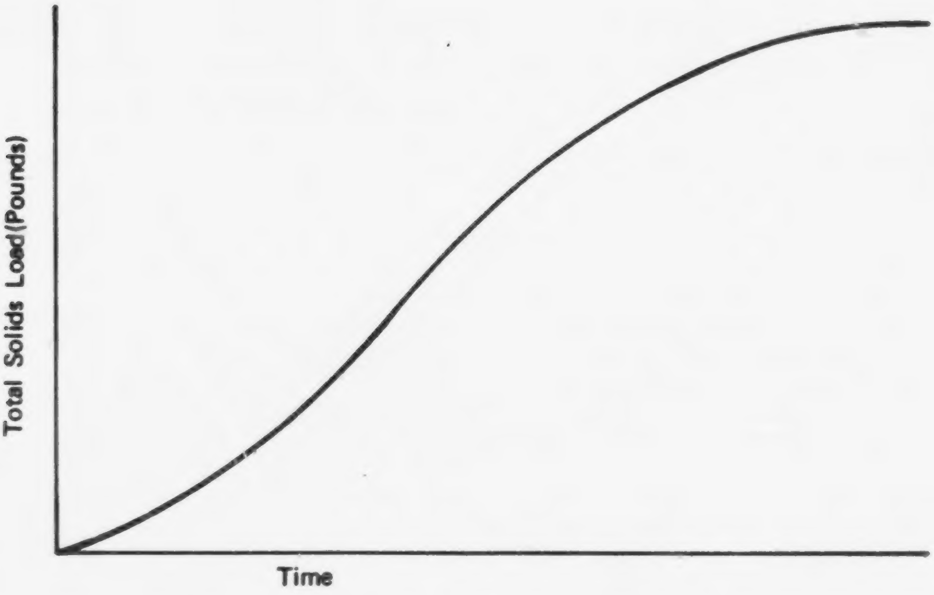


Figure 15b. A Sample Loadograph

The major limitation of the above relationship is that it can be applied only to situations where the runoff rate is constant. Unfortunately, this does not entirely hold true for street surface runoff during a particular storm event. The actual phenomenon is graphically portrayed in a street surface hydrograph where there is a rising and receding limb at the start and finish, respectively, of a rain event. After observing a typical street surface hydrograph, it becomes obvious that runoff is not constant at the start or finish of a rain event. Therefore, the previous equation must be simplified according to the fundamental definition of numerical differentiation:

$$P_o - P = \Delta P = (4.6\ r_{avg}\ P_o)\ \Delta t$$

The above relationship is valid for a particular time interval, Δt. The term, r_{avg}, is the average street surface runoff within the time interval, P_o is the amount of pollutants at the start of the time interval, P is the amount of pollutants at the end of the time interval, and $P_o - P$ or ΔP is the increment of pollutants removed during the time interval.

The above equation can be used in conjunction with the street surface hydrograph and the impervious area hydrograph of a study area to develop a pollutograph and a loadograph. Utilizing the accompanying worksheet (Figure 16a), the procedure is as follows:

(1) Utilizing the respective area hydrographs, select an appropriate time interval Δt by dividing the time base of both the impervious area hydrograph and the street surface hydrograph into approximately 20 equal time intervals which are convenient to use, such as 10 minutes, 20 minutes, 30 minutes, etc. A time interval of 10 minutes would be appropriate for a hydrograph with a time base of about 200 minutes.

(2) Determine the volume of impervious area runoff and the volume of street surface runoff within each time interval (obtained from each respective hydrograph and expressed as cubic feet per second) by the time interval (expressed as seconds). The calculated volumes of runoff will be expressed in cubic feet.

FIGURE 16a.

POLLUTOGRAPH AND LOADOGRAPH WORKSHEET

1	2	3	4	5	6	7	8
	STREET SURFACE RUNOFF						
Δt (min)	VOLUME (cu ft)	r_{avg} (in./hr)	P_o (lb)	ΔP (lb)	$\Sigma\Delta P$ (lb)	TOTAL VOLUME (cu ft)	TOTAL SOLIDS CONCENTRATION (mg/ℓ)

(3) Determine the average street surface runoff rate, r_{avg}, by dividing the volume of street surface runoff in each time interval by the product of [Δt (expressed as minutes) times the amount of street surface within the study area (expressed as acres) times the constant 60].

(4) The value of P_o for the first time interval can be determined by multiplying the contaminant load (expressed as pounds per acre of street surface) by the amount of street surface area (expressed as acres). Values of P_o for subsequent time intervals can be determined by subtracting the P value of the previous time interval from the P_o value of the previous time interval.

(5) Values of ΔP for each time interval can be determined from the previously described pollutant removal equation.

(6) Add each calculated value of ΔP to the summation of ΔP values.

(7) The concentration of total solids for each time interval can be determined by dividing the value of ΔP by the volume of impervious area runoff and multiplying the result by 16,000. It should be explained that runoff from total impervious area is used in step 7 in contrast to steps 3 through 6 when only the street surface runoff is utilized. The reason for doing so is obvious because essentially all urban contaminants are assumed to derive from street surfaces and they are removed by street surface runoff. These contaminants mix with the total impervious runoff flowing through gutters and sewers finally, neglecting the runoff contribution from pervious areas.

Using the above procedure, a series of values presenting the total solids concentration and the accumulative solids load at corresponding time intervals can be calculated and plotted against time. The graphical plot of concentration versus time represents the resultant pollutograph while the graphical plot of load versus time represents the resultant loadograph. The combination of an impervious area hydrograph, a pollutograph, and a loadograph superimposed upon the same coordinate system shall subsequently be referred to as a quantity/quality hydrograph as shown in Figure 16b.

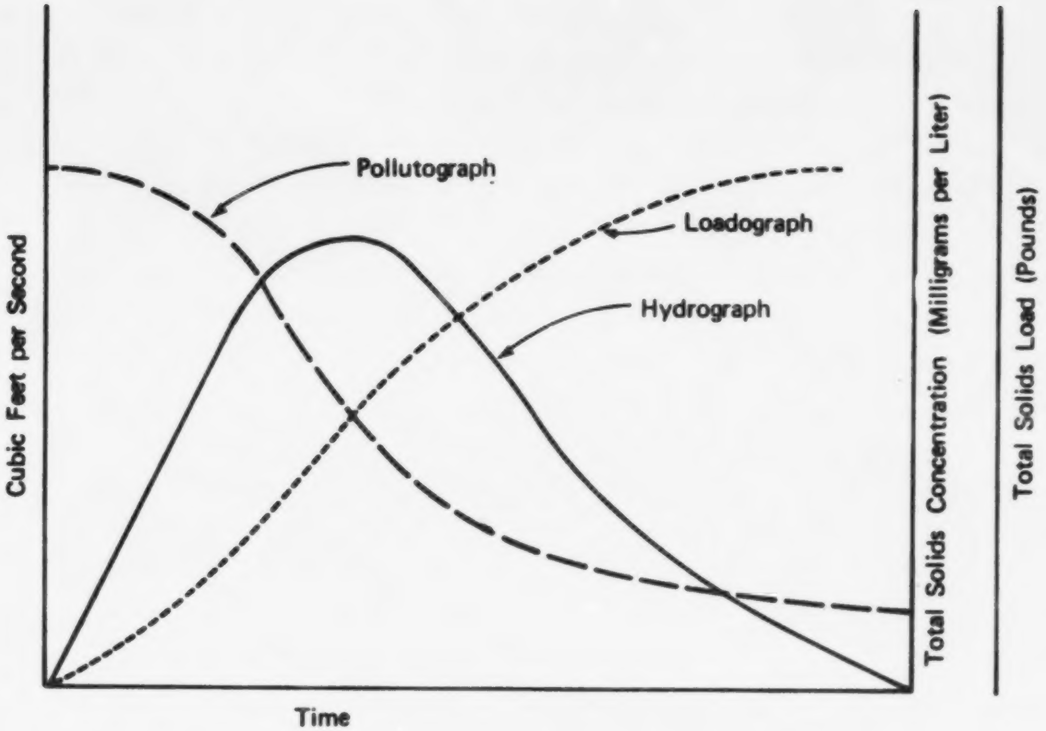


Figure 16b. A Sample Quantity/Quality Hydrograph Comprising a Hydrograph, a Pollutograph, and a Loadograph

A quantity/quality hydrograph describes runoff flow, pollutant concentration, and pollutant load as a function of time. Since it is not feasible to treat or store extremely large amounts of runoff resulting from exceptionally severe storms, a quantity/quality hydrograph enables one to focus attention on the most polluted portions of the runoff.

The development of a quantity/quality hydrograph is based on the assumption that runoff will remove all size particles at approximately the same rate (i.e., the rate of contaminant removal is independent of particle size) even though each pollutant may not be equally distributed over all particle size ranges. This assumption permits the development of the quantity/quality hydrograph based on total solids concentration, which can then be multiplied by a proportionality factor to determine single pollutant concentrations. The alternative would be to develop quantity/quality hydrographs for each pollutant under consideration which would not significantly increase validity but would greatly add to the work load. The assumption was supported by the results of the URS Research Company study of the "Water Pollution Aspects of Street Surface Contaminants."

An example of developing a pollutograph and a loadograph is given in Example 7, Section II.

6.0 QUANTITY/QUALITY HYDROGRAPHS

The procedures thus far presented enable the user to develop a quantity/quality hydrograph for an entire study area or for individual subareas. The ordinates of a quantity/quality hydrograph represent values of runoff flow, total solids concentration, and accumulative solids load at the inlet of the study area (i.e., the downstream location where the main drainage channel intersects the perimeter of the study area).

At this point, several more analytical tools are required for one to complete an assessment of urban runoff. These analytical tools will be provided within the following sections.

6.1 Method of Routing Quantity/Quality Hydrographs

No analytical techniques have thus far been presented to enable the user (1) to combine the quantity/quality hydrographs of two or more subareas into a single composite quantity/quality hydrograph representing an entire study area and (2) to modify the time base of the study area quantity/quality hydrograph such that it represents the quantity and quality characteristics of runoff at an outfall or point of discharge into a receiving water (as opposed to the inlet of the study area). The following discussion describes a "routing" technique which enables the user to accomplish both of these tasks.

Consider a hypothetical study area (Figure 17) consisting of two identical subareas. The respective inlets are identified as inlets 1 and 2 while D represents the point of discharge. The flow and quality characteristics of runoff entering inlets 1 and 2 at time t can be expressed as:

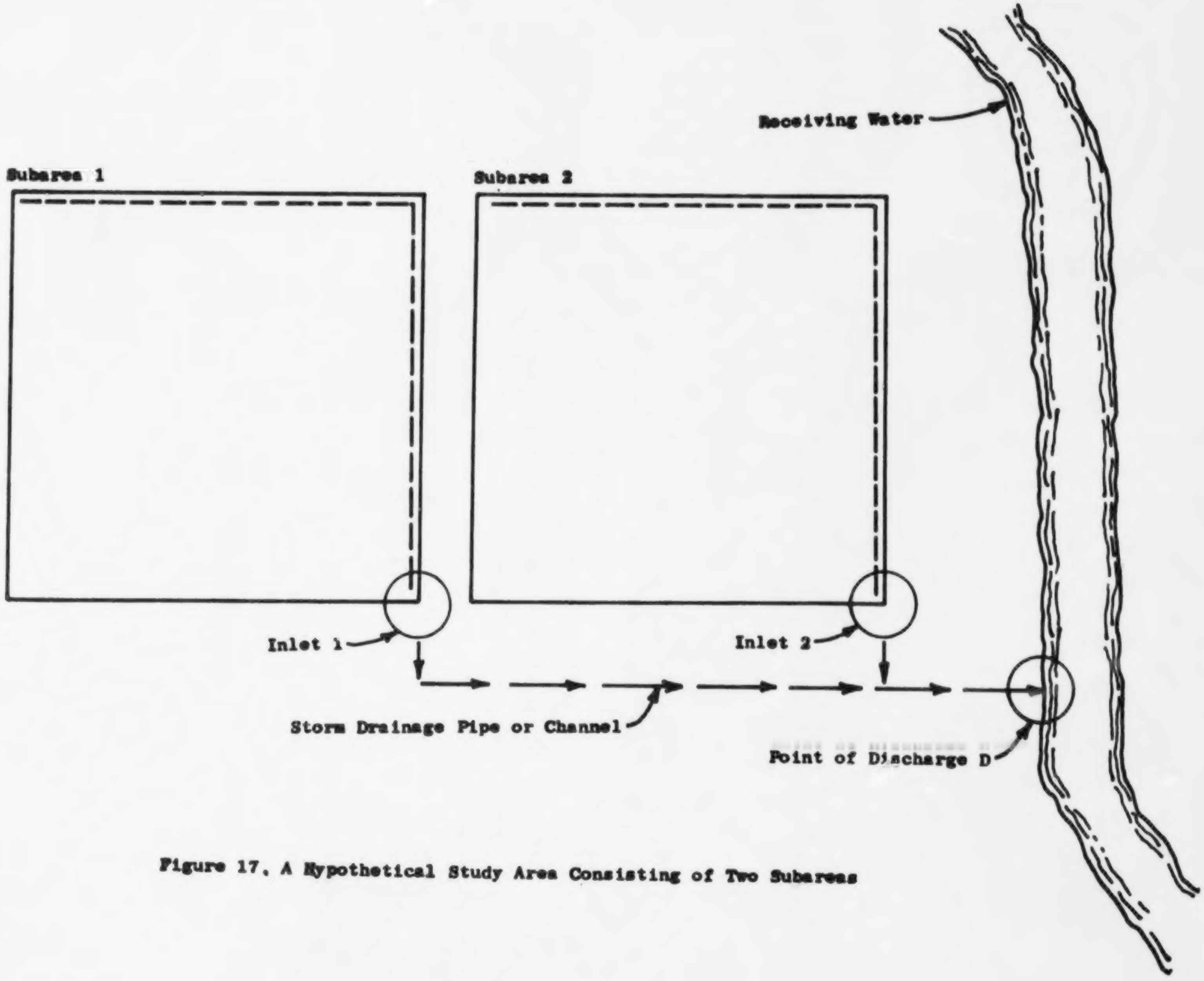

Receiving Water
Subarea 1
Subarea 2
Inlet 1
Inlet 2
Storm Drainage Pipe or Channel
Point of Discharge D

Figure 17. A Hypothetical Study Area Consisting of Two Subareas

$$F_{\text{inlets},\, t} = F_{1,t} + F_{2,t}$$

$$Q_{\text{inlets},\, t} = \frac{F_{1,t}Q_{1,t} + F_{2,t}Q_{2,t}}{F_{1,t} + F_{2,t}}$$

$$L_{\text{inlets},\, t} = L_{1,t} + L_{2,t}$$

where F = flow in cubic feet per second
Q = pollutant concentration in milligrams per liters
L = pollutant load in pounds

However, the instantaneous flow entering inlets 1 and 2 at time t will not arrive at point D at the same identical time. The flow entering inlet 1 at time t will arrive at point D at a later time than the flow entering inlet 2 at time t. This phenomenon is obvious since flow must travel a greater distance from inlet 1 to D than from inlet 2 to D. Therefore, a time correction factor is required to compensate for this lag.

"Lag time" will be defined as the time of travel for stormwater to flow from an inlet to the point of discharge. Lag time, Δt, is primarily a function of the distance of travel and the diameter and slope of the storm drainage pipe or channel. The nomograph in Figure 18 can be used to estimate lag time.

The nomograph in Figure 18 is based upon a typical storm drainage pipe or channel fabricated from ordinary concrete. If the pipe or channel is fabricated from another material, the estimated lag time derived from the nomograph must be multiplied by an appropriate adjustment factor from Table 10.

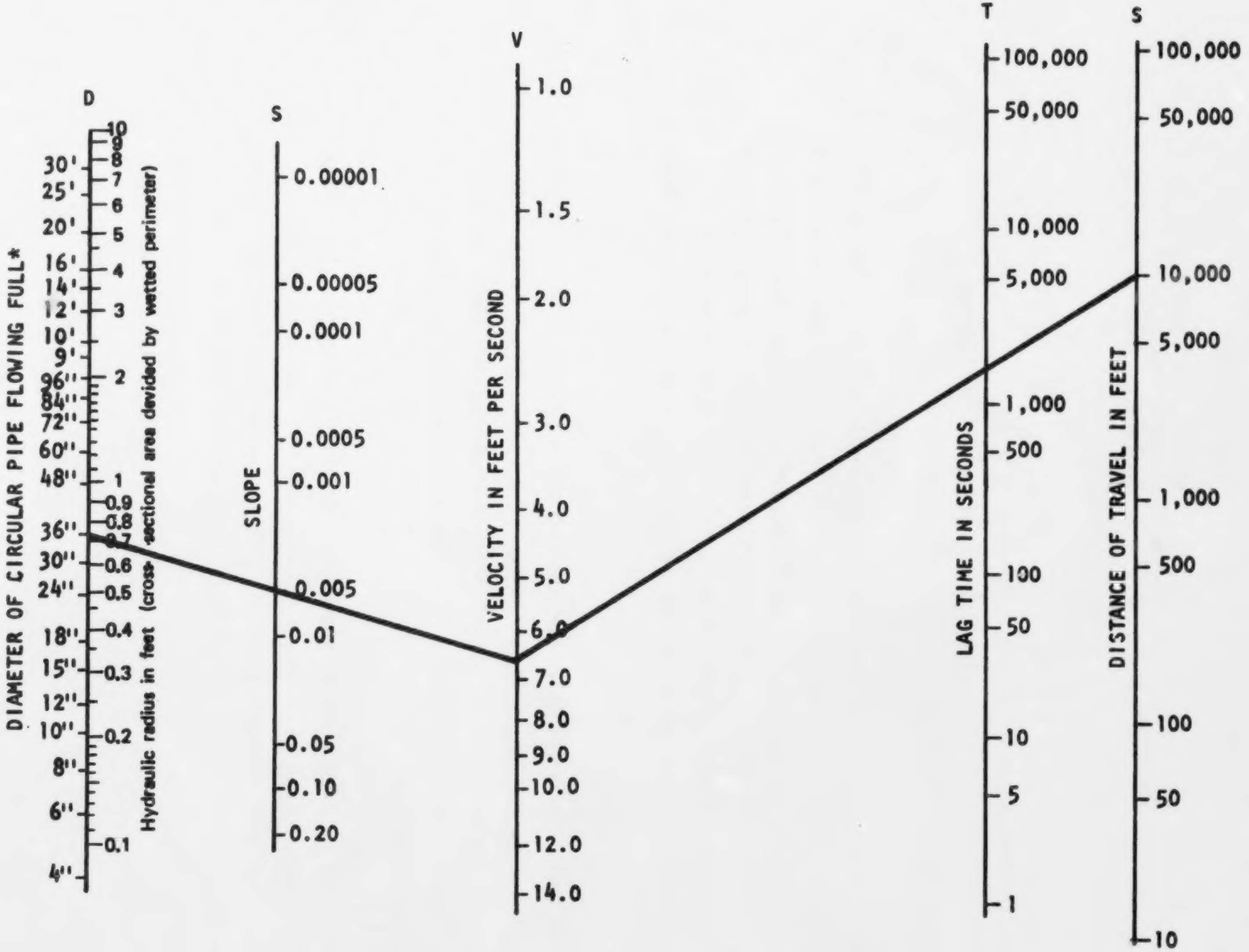


Figure 10. Determination of Lag Time

* If the depth of the water flowing in the pipe is at least 30% of the pipe diameter, the resulting estimate of lagtime will at least be within ± 20%.

Table 10. LAG TIME ADJUSTMENT FACTORS

CHANNEL MATERIAL	ADJUSTMENT FACTOR
Plastic, glass, drawn tubing	0.69
Neat cement, smooth metal	0.77
Planed timber, asbestos pipe	0.85
Wrought iron, welded steel, canvas	0.92
Ordinary concrete, asphalted cast iron	1.0
Unplaned timber, vitrified clay	1.07
Cast-iron pipe	1.15
Riveted steel, brick	1.23
Rubble masonry	1.30
Smooth earth	1.38
Firm gravel	1.54
Corrugated metal pipe	1.69
Natural channels in good condition	1.92
Natural channels with stones and weeds	2.69
Very poor natural channels	4.62

Applying the concept of lag time to the hypothetical study area:

Δt_1 = lag time from inlet 1 to D

Δt_2 = lag time from inlet 2 to D

Accordingly, the accumulative flow and quality of runoff at time t at the point of discharge D can be expressed by:

$$F_{D,t} = F_{1,t - \Delta t_1} + F_{2,t - \Delta t_2}$$

$$Q_{D,t} = \frac{(F_{1,t - \Delta t_1})(Q_{1,t - \Delta t_1}) + (F_{2,t - \Delta t_2})(Q_{2,t - \Delta t_2})}{(F_{1,t - \Delta t_1}) + (F_{2,t - \Delta t_2})}$$

$$L_{D,t} = L_{1,t - \Delta t_1} + L_{2,t - \Delta t_2}$$

The above equations allow the user to combine individual quantity/quality hydrographs of two or more subareas into a composite quantity/quality hydrograph representing the entire study area. A value of $F_{D,t}$, $Q_{D,t}$, and $L_{D,t}$ can be calculated for each time value, t, by substituting values of F, Q, and L obtained from the subarea hydrographs into the above equations. The composite quantity/quality hydrograph can be developed by plotting values of $F_{D,t}$, $Q_{D,t}$, and $L_{D,t}$ versus time as shown in Figure 19. It may be required to plot many data points to obtain a high degree of accuracy. However, if a rough approximation will suffice, a few data points may adequately approximate the shape of a composite quantity/quality hydrograph.

An example of the above routing technique is given in Example 8, Section II.

The above application of the routing technique was concerned with combining subarea quantity/quality hydrographs into a composite quantity/quality hydrograph portraying the characteristics of runoff from an entire study area at a point of discharge. However, if the assessment conducted by the user does not require dividing a study area into subareas, part of the routing technique can be used to simply modify the time base of a study area quantity/quality hydrograph in order to portray the characteristics of runoff at a point of discharge. The procedure consists of using the nomograph shown in Figure 18 to estimate the lag time from the inlet of the study area to the point of discharge. Subsequently, the entire quantity/quality hydrograph is shifted along the time axis in a positive direction for a distance equal to the lag time.

6.2 Quality Composition of Runoff

The development of a quantity/quality hydrograph is based upon the removal of solids from urban land surfaces by runoff. Consequently, the quality ordinates portray the concentration and load of total solids.

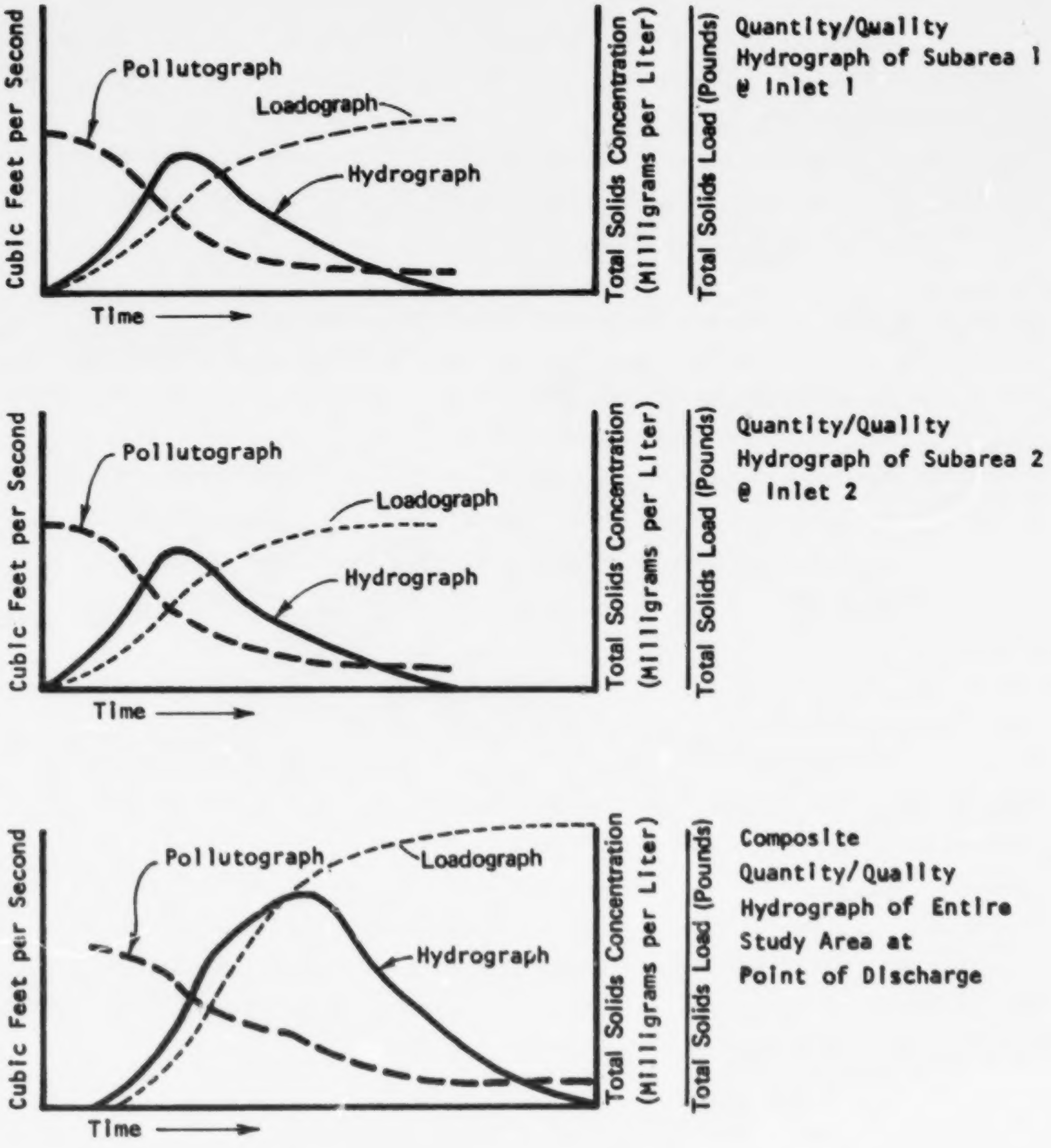


Figure 19. Development of a Composite Quantity/Quality Hydrograph by the Routing Techniques

However, total solids is not a useful quality parameter for evaluating the water pollution potential of urban runoff since the actual composition of the solids determines its pollutional characteristics.

Previous material provided means to estimate both a contaminant load and its corresponding composition for a study area or a subarea. Data regarding the composition of the contaminant load was generally expressed in terms of micrograms per gram (parts per million) or micrograms per kilogram.(parts per billion).

In order to realistically evaluate the water pollution potential of urban runoff, the total solids ordinates of each quantity/quality hydrograph must be modified to reflect other quality parameters such as BOD, COD, PO_4, NO_3, etc. The required modification consists of adjusting the total solids ordinates by applying the composition data of a specific quality parameter as a proportionality factor. A sample quantity/quality hydrograph modified to reflect several quality parameters is shown in Figure 20.

The choice of which quality parameters to select for evaluation is dependent upon receiving water characteristics and standards. It is the responsibility of the user to designate which quality parameters to select for evaluation purposes. For example, one may select BOD as the quality parameter for evaluating a receiving water with low levels of dissolved oxygen while one may select PO_4 and NO_3 as the quality parameters for evaluating a receiving water which has a significant potential for eutrophication. The concept of modifying a quantity/quality hydrograph to reflect other quality parameters is demonstrated in the latter part of Example 10.

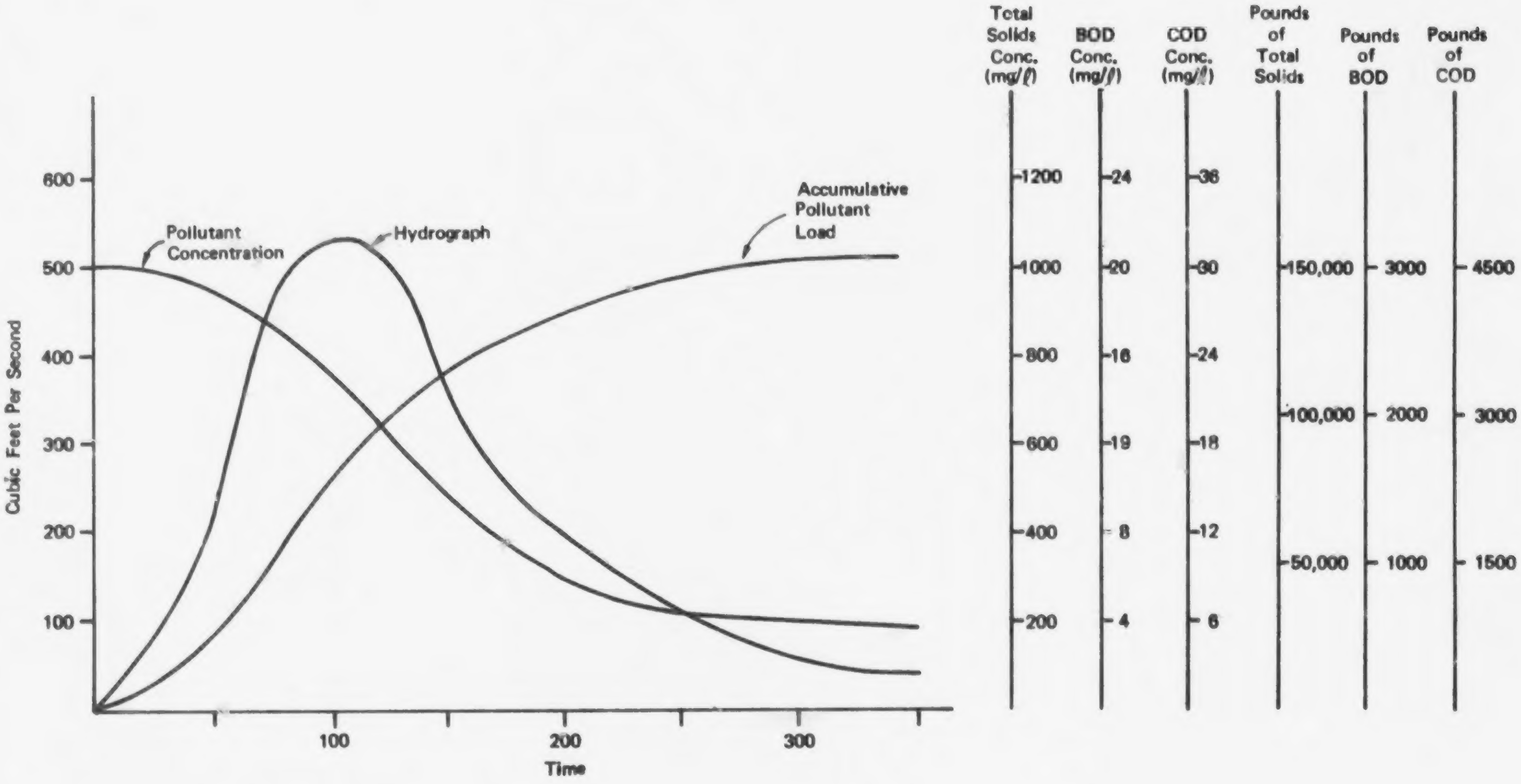


Figure 20. A Sample Quantity/Quality Hydrograph Reflecting Several Quality Parameters

7.0 ANALYTICAL PROCEDURES FOR THE ASSESSMENT OF URBAN RUNOFF QUANTITY AND QUALITY

7.1 Level I

A simple, first-glance assessment of the water pollution aspects of urban runoff is to consider only (1) the volume of impervious runoff and (2) the amount of street surface contaminants removed by street surface runoff. In turn, the rate of runoff with respect to time is ignored. The procedure is as follows:

(1) Describe the specified study area according to the following characteristics: study area size (acres), amount of interconnected impervious area within study area (acres), amount of street surface area within study area (acres), average slope of main drainage channel (feet/feet).

(2) Determine an appropriate contaminant loading for street surfaces within the study area.

(3) Select a storm event according to the criteria presented and compute the impervious runoff rate.

(4) The volume of runoff from the interconnected impervious area can be estimated by the following:

Impervious Volume of Runoff (cf) = Runoff Rate (in./hr) X
Interconnected Impervious Area (acres) X
1,815

(5) The percentages of street surface contaminants which will be removed by various combinations of runoff rate and runoff duration are given in Table 9. The amount of contaminants removed from the study area by the selected runoff rate/duration can be estimated by the following:

Amount of Contaminant Removal (lb) = Contaminant Load Per Acre of Street Surface (lb/acre) X
Amount of Street Surface Area (acres) X
Percent Contaminant Removal/100

(6) The average total solids concentration of runoff can be described by the following expression:

$$\text{Total Solids Concentration (mg/}\ell\text{)} = \frac{\text{Amount of Contaminant Removal (lb)}}{\text{Impervious Volume of Runoff (cf)}} \times 16{,}019$$

(7) The average concentration of other pollutants can be determined by multiplying the average total solids concentration by the composition data of specific quality parameters.

A Level I assessment is demonstrated by Example 9, Section II.

7.2 Level II

An intermediate level of assessment can be used to investigate an entire urban watershed or a portion of an urban watershed. The characteristics of the study area are considered homogeneous and a single quantity/quality hydrograph is developed for the entire study area. The procedure is as follows:

(1) Describe the specified study area according to the following characteristics: study area size (acres), amount of interconnected impervious area within study area (acres), amount of street surface area within study area (acres), length of main drainage channel (feet), and average slope of main drainage channel (feet/feet).

(2) Determine an appropriate contaminant loading for street surfaces within the study area.

(3) Select a storm event according to the criteria presented and compute the impervious runoff rate.

(4) Develop a 30-minute unit hydrograph for both the interconnected impervious area and the street surface area within the study area by using the equations derived by Espey.

(5) Modify the impervious area unit hydrograph and the street surface unit hydrograph to reflect the computed impervious runoff rate.

(6) Develop a corresponding pollutograph and loadograph by using the appropriate procedure in conjunction with the impervious area hydrograph and the street surface hydrograph.

(7) Plot the impervious area hydrograph, pollutograph, and loadograph upon the same coordinate system to produce a quantity/quality hydrograph for the study area.

(8) Modify the total solids ordinates of the quantity/quality hydrograph to reflect other quality parameters of concern.

The procedure for a Level II assessment is demonstrated by Example 10, Section II.

7.3 Level III

A thorough level of assessment can be used to investigate a study area consisting of two or more urban watersheds, portions of two or more urban watersheds, or two or more homogeneous portions of an urban watershed. The study area is divided into two or more subareas. A quantity/quality hydrograph is developed for each subarea, and subsequently, the routing technique is used to develop a single composite quantity/quality hydrograph representing the entire study area. The procedure is as follows:

(1) Divide the study area into subareas.

(2) Describe each subarea according to the following characteristics: subarea size (acres), amount of interconnected impervious area within subarea (acres), amount of street surface area within subarea (acres), length of main drainage channel (feet), and slope of main drainage channel (feet/feet).

(3) Determine an appropriate contaminant loading for street surfaces within each subarea.

(4) Select a storm event according to the criteria presented and compute the impervious runoff rate for each subarea. The impervious runoff rate for each subarea will be

identical if the slope of each subarea is the same. If the slopes differ, the computed runoff rate will be highest for the subarea with the greatest slope.

(5) For each subarea, develop a 30-minute unit hydrograph for both impervious area and street surfaces by utilizing the equations derived by Espey.

(6) For each subarea, modify the impervious area unit hydrograph and the street surface unit hydrograph to reflect the computed impervious runoff rate pertaining to each subarea.

(7) Develop a corresponding pollutograph and loadograph for each subarea by using the appropriate procedure in conjunction with the impervious area hydrograph and street surface hydrograph of each subarea.

(8) For each subarea, plot the corresponding impervious area hydrograph, pollutograph, and loadograph upon a coordinate system to produce a quantity/quality hydrograph representing each subarea.

(9) Modify the total solids ordinates of each subarea quantity/quality hydrograph to reflect other quality parameters of concern. If the contaminant load for for each subarea is identical, this modification can be made to the composite quantity/quality hydrograph after it is developed in the next step.

(10) Transform the characteristics of all subarea quantity/quality hydrographs into a single composite quantity/quality hydrograph representing the entire study area by utilizing the routing technique.

The procedure for a Level III assessment essentially consists of conducting a Level II assessment for each subarea and, subsequently, utilizing the routing technique to combine the subarea quantity/quality hydrographs into a single composite one. Therefore, the demonstration of a Level II assessment by Example 10 and the routing technique by Example 8 should provide adequate insight into the procedure for a Level III assessment.

Section I

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1. Chow, Ven Te, Handbook of Applied Hydraulics, 1964.

2. Espey, W.H. and D.E. Winslow, The Effects of Urbanization on Unit Hydrographs for Small Watersheds, 1968.

3. Metcalf and Eddy, Inc., Storm Water Management Model, Vols. I-IV, EPA, July 1971 - October 1971.

4. Sartor, J.D. and G.B. Boyd, Water Pollution Aspects of Street Surface Contaminants, EPA, Research and Monitoring, Envir. Protection Tech. Series, EPA - R2-72-081, Nov. 1972.

Section II

EXAMPLE PROBLEMS

Section II

EXAMPLE PROBLEMS

The example problems presented in this section will assist the user in determining the water pollution aspects of urban runoff.

The following lists the example problems presented in this section:

Example 1: Characterization of a study area
Example 2: Determination of contaminant loading
Example 3: Determination of runoff rate by runoff coefficient
Example 4: Determination of runoff rate by composite runoff coefficient
Example 5: Selection of storm event
Example 6: Development of a unit hydrograph
Example 7: Development of a pollutograph and loadograph
Example 8: Utilization of routing technique
Example 9: A Level I assessment of urban runoff
Example 10: A Level II assessment of urban runoff

EXAMPLE 1

A 27-acre urban watershed is defined as a study area as shown in Figure 21. Determine the following study area characteristics:

- Average Imperviousness
- Length of Main Drainage Channel
- Average Slope of Main Drainage Channel

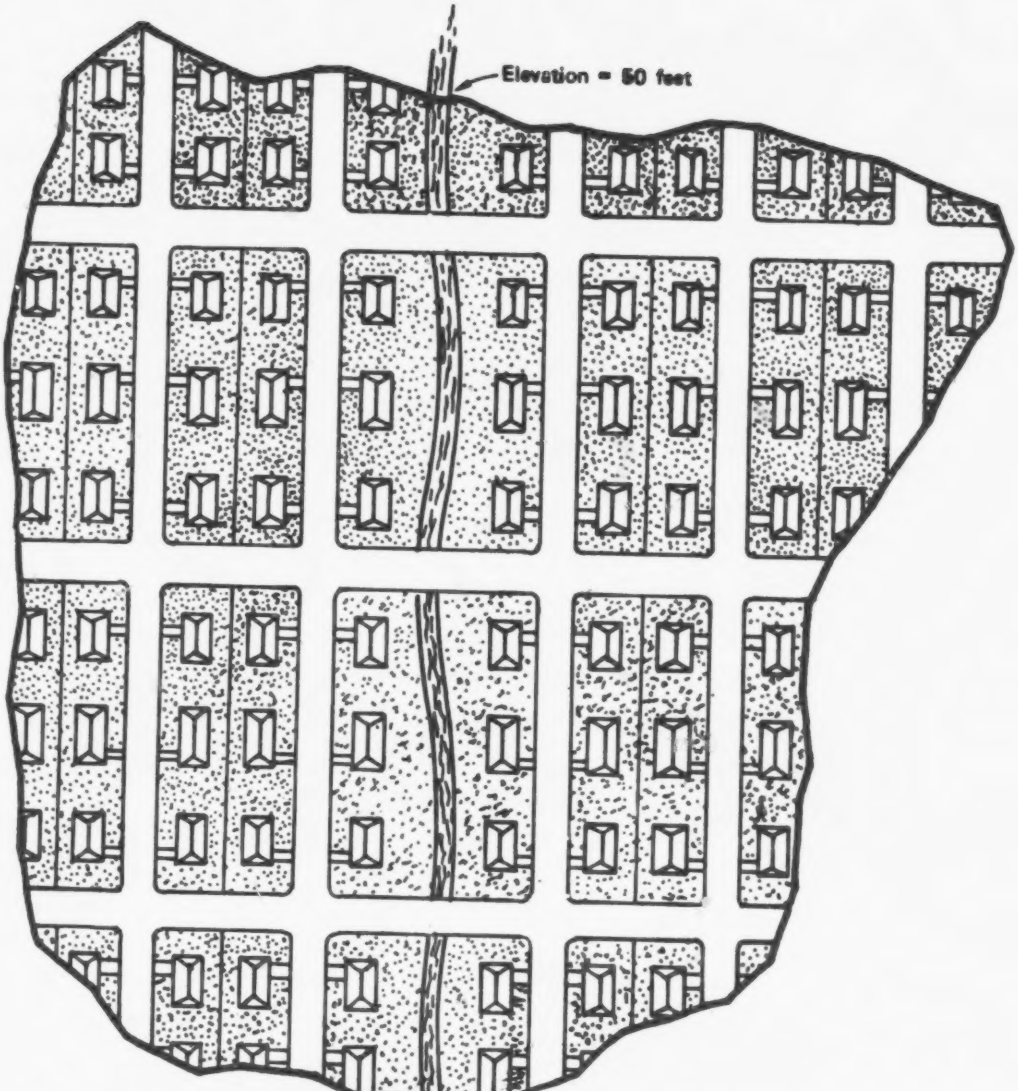

Elevation = 50 feet
Elevation = 10 feet
Pervious
Impervious
Main Drainage Channel

Figure 21. Sample Study Area for Example 1

Scale: 1"=200'

Average Imperviousness

The hypothetical study area shown in Figure 21 consists of both impervious and pervious surfaces. For the purpose of this example, impervious surfaces will only include rooftops, driveways, and street surfaces. Furthermore, it is assumed that runoff from rooftops will drain onto driveways which, in turn, drain onto street surfaces.

Only impervious area is considered in the computations, hence imperviousness is taken to be 100 percent. From Figure 21, it is estimated that the study area includes about 13 acres of impervious surface area out of a total area of 27 acres. Impervious area is comprised of two parts, i.e., street surface consisting of 10 acres and others, 3 acres.

Length of Main Drainage Channel

Using the scale indicated in Figure 21, the length of the main drainage channel is estimated to be about 1,200 feet.

Average Slope of Main Drainage Channel

The elevation varies from 50 feet to 10 feet over the length of the main drainage channel. Accordingly, the average slope of the channel can be estimated by:

$$\frac{50 \text{ ft} - 10 \text{ ft}}{1200 \text{ ft}} = \frac{40 \text{ ft}}{1200 \text{ ft}} = .033$$

EXAMPLE 2

Predict the load per acre five days after a rain and the composition of solids present on an asphalt street in a new residential area in Portland, Oregon, where the average daily traffic is less than 500.

Solution: Following the procedure given, the solution is obtained in these steps:

1. Use only substitutions at the 95 percent confidence level shown in Table 5.

2. Present a range of possible data based on the loading rate only:

    a. The area selected is residential. Move upward to the residential land use category. No loading substitution is permissible. One could substitute other compositional parameters but we are looking for a row that has a permissible loading substitution.

    b. Portland is in the northwest. Move upward to the northwest climate category. A loading substitution is permitted. After making all permissible substitutions into the row labeled "All Data," the new row is shown in Table 11.

3. Since there are no other permissible substitutions of the loading rate available under any other category by which the site may be classified, present two tables: the means of the set of all data with no substitutions and Table 11.

4. The loading rate in Table 11 is lower than the mean of all data and probably better represents the real situation in Portland, Oregon. For all later calculations, use Table 11.

5. Convert the loading rate to load per curb mile as follows:

    30 lb/curb mi/day x 5 days = 150 lb/curb mi

Table 11. SAMPLE ROW OF LOADING AND COMPOSITION DATA

Lbs/Curb Mi/Day	Concentrations in Micrograms per Gram of Dry Solid								
Loading	BOD_5	COD	OPO_4	TPO_4	NO_3	NH_4	ORGN	CD	CR
30*	19,900	140,000	1,280	2,930	804	2,640	2,950	3.4	211

Concentrations in Micrograms per Gram of Dry Solid							#/Gram	
CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
104	34,500*	1,810	418	35	10*	480*	6.8E5*	1.1E4*

Note: Substitutions are indicated by an asterisk.

6. Convert the load to load/acre as follows, using the curb mile density factor in Table 2:

150 lb/curb mi x 0.54 curb mi/acre = 81.0 lb/acre

EXAMPLE 3

An urban watershed consists of 200 acres of land with essentially all impervious surface and a relatively flat slope.

a. What is the rate of runoff resulting from a storm with an intensity of 0.5 in./hr which lasts for 1 hour?

$$R = kP$$

$$k = 0.80 \text{ from Table 8}$$

$$R = (0.80)\ (0.5\ \text{in./hr}) = \underline{0.4\ \text{in./hr}}$$

b. What rainfall intensity will produce a runoff rate of 0.5 in./hr from the same watershed?

$$R = kP$$

$$P = \frac{R}{k}$$

$$P = \frac{(0.5\ \text{in./hr})}{0.80} = \underline{0.63\ \text{in./hr}}$$

EXAMPLE 4

An urban watershed consists of 400 acres of land with a moderate slope. The watershed comprises 200 acres of impervious surface and 200 acres of pervious surface with lawns and heavy soils. What rate of runoff will result from a storm with an intensity of 0.33 in./hr which lasts for 45 minutes? (Only impervious area is considered as explained earlier.)

$$k_{imp} = 0.85 \text{ from Table 8.}$$

$$R = kP$$

$$R = (0.85)\ (0.33\ \text{in./hr}) = \underline{0.28\ \text{in./hr}}$$

EXAMPLE 5

Select a 1-year storm of 30 minutes duration for a study area in Portland, Oregon and determine the runoff rate and duration resulting from the selected storm event. The runoff coefficient for the study area is 0.9 considering only the impervious areas.

Solution

Figure 4 reveals that a 1-year storm of 30 minutes duration in the vicinity of Portland, Oregon will contribute a total of 0.4 inches of rainfall. Since this 0.4 inches of rainfall occurs over a 30-minute interval, the average rainfall intensity of the storm will be 0.8 inches per hour.

The runoff rate of the selected storm event can be determined as follows:

$$R = kP$$

$$R = 0.9\ (0.8\ \text{inches/hour})$$

$$R = 0.72\ \text{inches per hour}$$

Therefore, the resultant runoff rate is 0.72 inches per hour while the resultant runoff duration is 30 minutes. It should be noted that time-base of the hydrograph will extend over a longer period than 30 minutes.

EXAMPLE 6

An urban study area consists of a rectangular parcel of land with a length of 1.0 mile and a width of 0.5 mile. The length of the main drainage channel is 7,000 feet, the average slope of the main drainage channel is 2 ft/100 ft and the average imperviousness is 55 percent.

(a) Develop a unit hydrograph for the impervious portion of the study area by using Espey's equations.

Slope (S)

$S = 2 \text{ ft}/100 \text{ ft} = 0.02$

Area (A)

$$A_{total} = \frac{(5280 \text{ ft})\ (2640 \text{ ft})}{43560 \text{ ft}^2 \text{ acre}} = 320 \text{ acres}$$

$$A_{imp} = 0.55 \times 320 = 176 \text{ acres}$$

Imperviousness (I)

$I = 100\%$

Length (L)

$L = 7{,}000 \text{ ft}$

Using Nomograph of Figure 7 in Conjunction with Figures 8 thru 11

$T_R = 27$ minutes

$Q = 259$ cfs

$T_B = 155$ minutes

$W_{50} = 37$ minutes

$W_{75} = 25$ minutes

The resultant hydrograph is shown in Figure 22a.

(b) Develop a unit hydrograph for the street surface portion of the study area assuming that street surfaces represent 35 percent of the study area.

Slope (S)

$S = 0.02$

Area (A)

$A_{\text{street surface}} = 320 \times 0.35 = 112$ acres

Imperviousness (I)

$I = 100\%$

Length (L)

$L = 7{,}000$ ft

Using Nomograph of Figure 7 in Conjunction with Figure 8 thru 11

$T_R = 27$ minutes

$Q = 165$ cfs

$T_B = 155$ minutes

$W_{50} = 37$ minutes

$W_{75} = 25$ minutes

The resultant hydrograph is shown in Figure 22b.

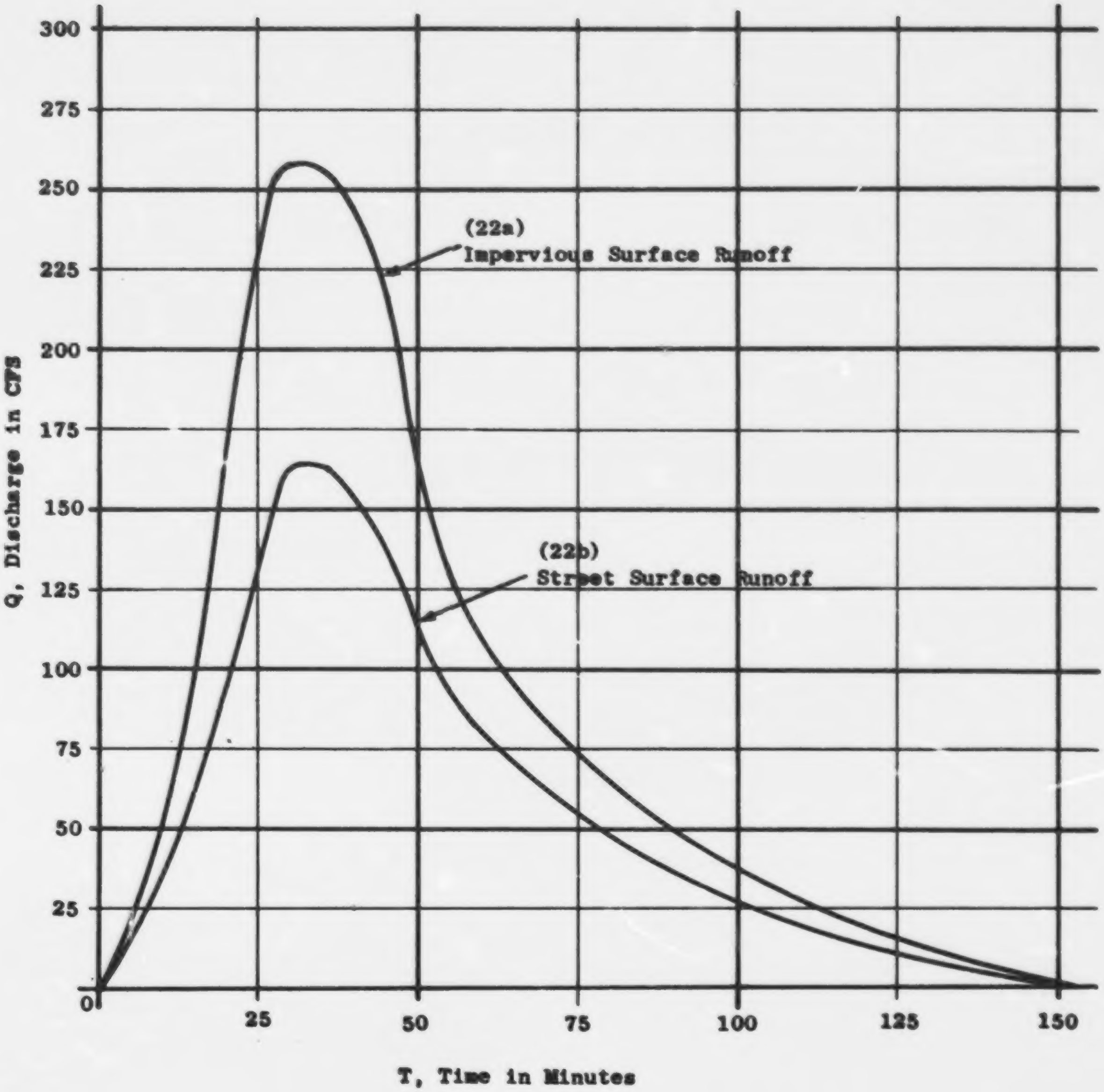


Figure 22. Unit Hydrographs Developed in Example 6

EXAMPLE 7

Using the hydrograph developed in Example 6 (Figure 22), develop a corresponding pollutograph and loadograph based on a contaminant loading of 500 lb/curb mile, if the length of all streets in the study area is 30 miles.

The general pollutograph equation is:

$$\Delta P = (4.6\ r_{avg}\ P_o)\ \Delta t$$

where ΔP = Amount of pollutants removed during the time interval, Δt

P_o = Amount of pollutants remaining at the beginning of the time interval, Δt

r_{avg} = Average runoff rate within the time interval, Δt

Curb mile = 30 X 2 = 60, P_o (initial pollutant load) = 500 X 60

= 30,000 lbs.

Values of total solids concentration and accumulative solids load are plotted against time, and the resultant pollutograph and loadograph are shown in Figure 23.

POLLUTOGRAPH AND LOADOGRAPH WORKSHEET

Δt (min)	STREET SURFACE RUNOFF VOLUME (cu ft)	STREET SURFACE RUNOFF r_{avg} (in./hr)	P_o (lb)	ΔP (lb)	$\Sigma \Delta P$ (lb)	TOTAL VOLUME (cu ft)	TOTAL SOLIDS CONCENTRATION (mg/ℓ)
0- 12.5	16,900	0.200	30,000	5,750	5,750	26,500	3,476
12.5- 25	72,000	0.850	24,250	19,750	25,500	112,500	2,812
25 - 37.5	122,500	1.446	4,500	4,500	30,000	192,000	375
37.5- 50	102,000	1.204	0	0	30,000	160,000	0
50 - 62.5	62,000	0.732	0	0	30,000	97,000	0
62.5- 75	12,000	0.500	0	0	30,000	66,000	0
75 - 87.5	30,000	0.354	0	0	30,000	47,500	0
87.5-100	21,700	0.256	0	0	30,000	34,000	0
100 -112.5	14,600	0.172	0	0	30,000	23,000	0
112.5-125	10,200	0.120	0	0	30,000	16,000	0
125 -137.5	6,100	0.072	0	0	30,000	9,500	0
137.5-150	2,900	0.034	0	0	30,000	4,500	0

Following equations have been used in preparing the above table.

$$\text{Volume} = Q_{avg} \times (\Delta t)_{min} \times 60$$

$$r_{avg}\ (\text{in./hr}) = \frac{\text{Volume (cu ft)}}{(\Delta t)_{min} \times A_{acres} \times (60.5)}$$

$$\Delta P = (4.6\ r_{avg}\ P_o) \times \frac{(\Delta t)_{min}}{60}$$

$$\text{Conc. } (\text{mg}/\ell) = \frac{\Delta P \times 16{,}019}{\text{Runoff Volume from Total Imp. Area}}$$

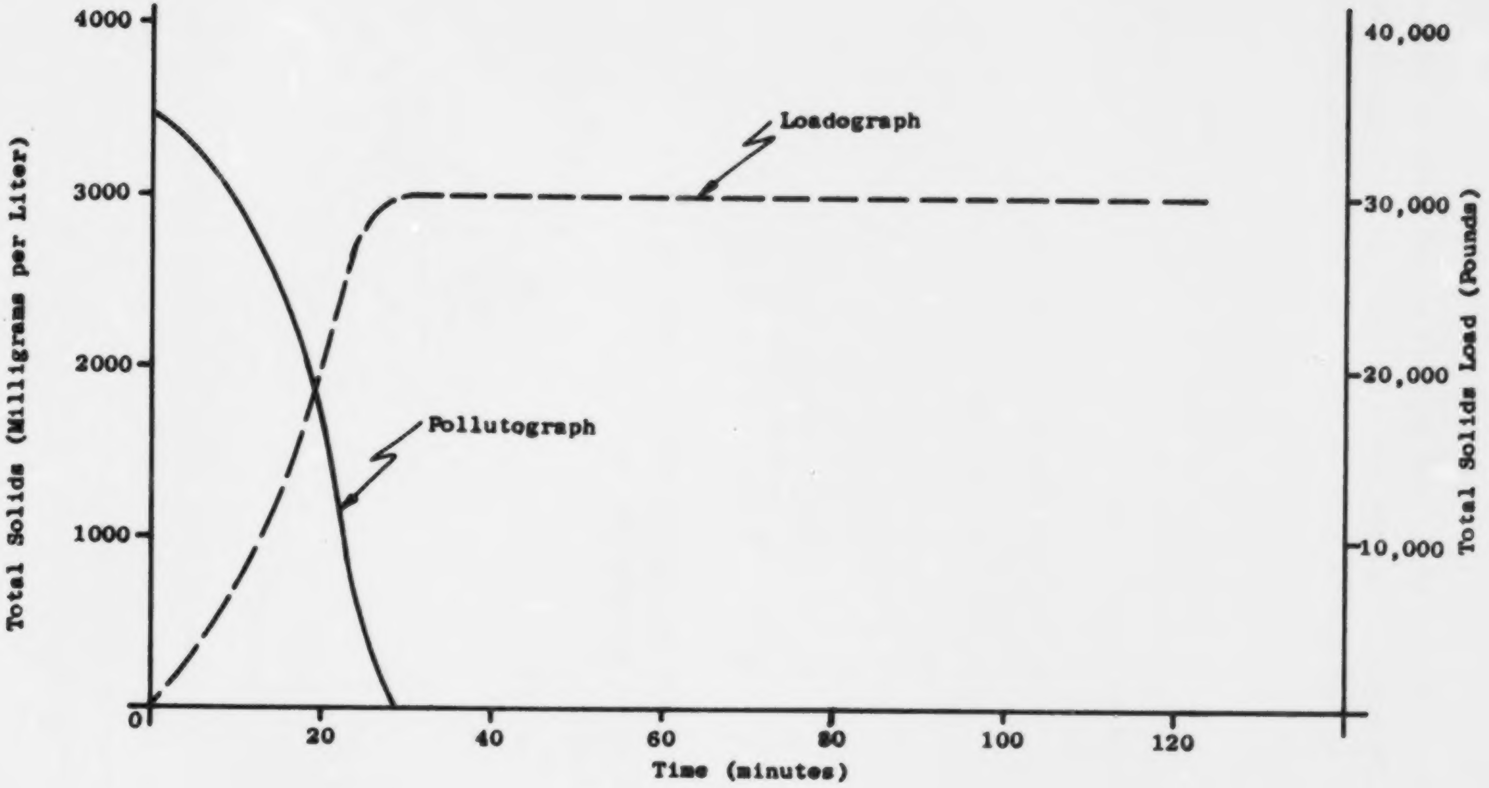


Figure 23. Pollutograph and Loadograph Developed in Example 7

EXAMPLE 8

A 300-acre parcel of urban land consists of 200 acres of industrial land use and 100 acres of residential land use as shown in Figure 24. Quantity/quality hydrographs which describe the two subareas are given in Figure 25.

Using the routing technique described in Section I, combine the quantity/quality characteristics of the two subareas into a composite quantity/quality hydrograph representing the entire study area.

Δt_1 = lag time from inlet 1 to D

Δt_2 = lag time from inlet 2 to D

From Figure 18 Nomograph:

$$\Delta t_1 = 510 \text{ sec} = 8.5 \text{ min}$$

$$\Delta t_2 = 300 \text{ sec} = 5.0 \text{ min}$$

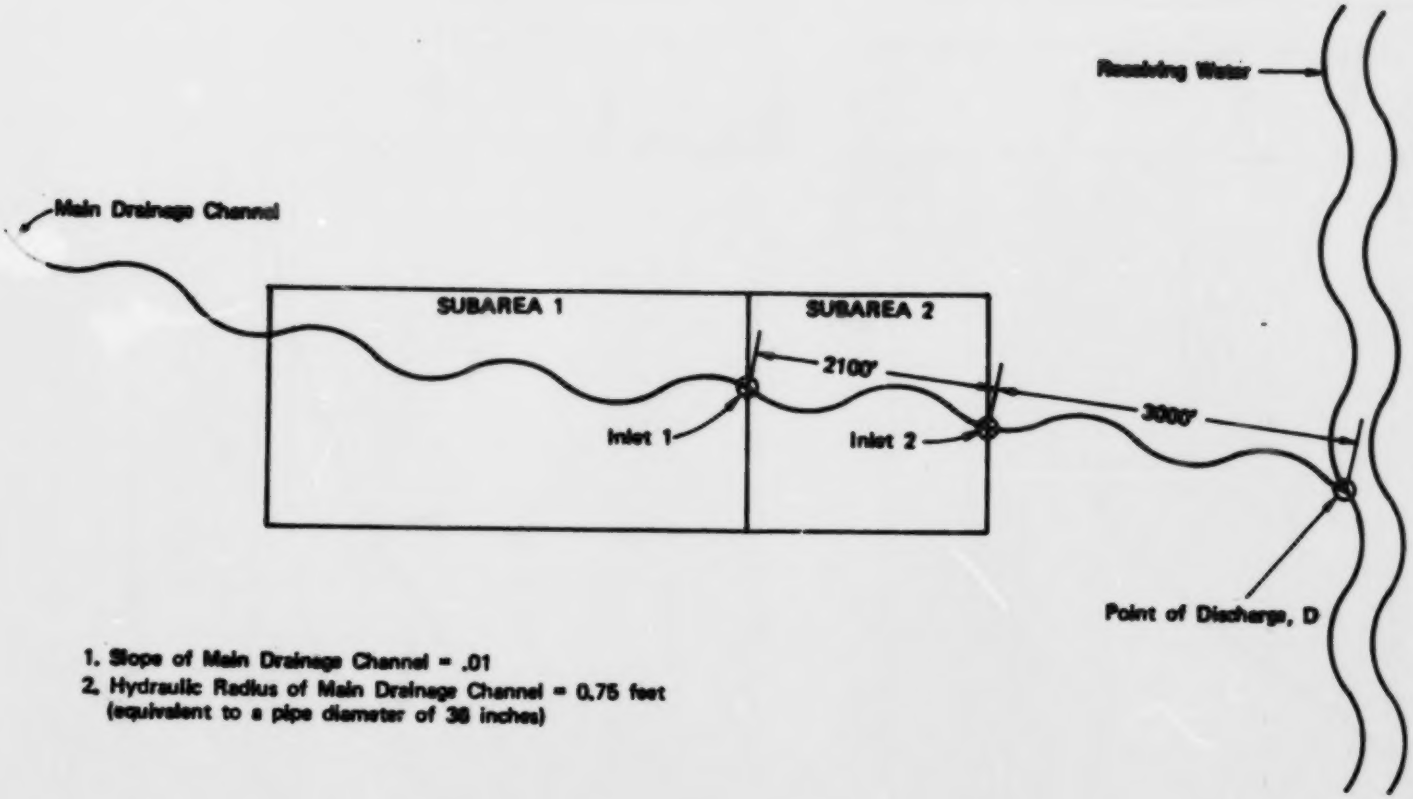
The accumulative flow and quality of runoff at time t at the point of discharge D can be expressed by:

$$F_{D,t} = F_{1,t-\Delta t_1} + F_{2,t-\Delta t_2}$$

$$Q_{D,t} = \frac{(F_{1,t-\Delta t_1})(Q_{1,t-\Delta t_1}) + (F_{2,t-\Delta t_2})(Q_{2,t-\Delta t_2})}{(F_{1,t-\Delta t_1}) + (F_{2,t-\Delta t_2})}$$

$$L_{D,t} = L_{1,t-\Delta t_1} + L_{2,t-\Delta t_2}$$

The composite quantity/quality hydrograph can be plotted by substituting values of flow and quality read from the subarea quantity/quality hydrographs into the above equations. A value for the composite flow and quality at time t can be ascertained by substituting the flow and quality of


Receiving Water
Main Drainage Channel
SUBAREA 1
SUBAREA 2
2100'
3000'
Inlet 1
Inlet 2
Point of Discharge, D

1. Slope of Main Drainage Channel = .01
2. Hydraulic Radius of Main Drainage Channel = 0.75 feet (equivalent to a pipe diameter of 38 inches)

Figure 24. Study Area of Example 8

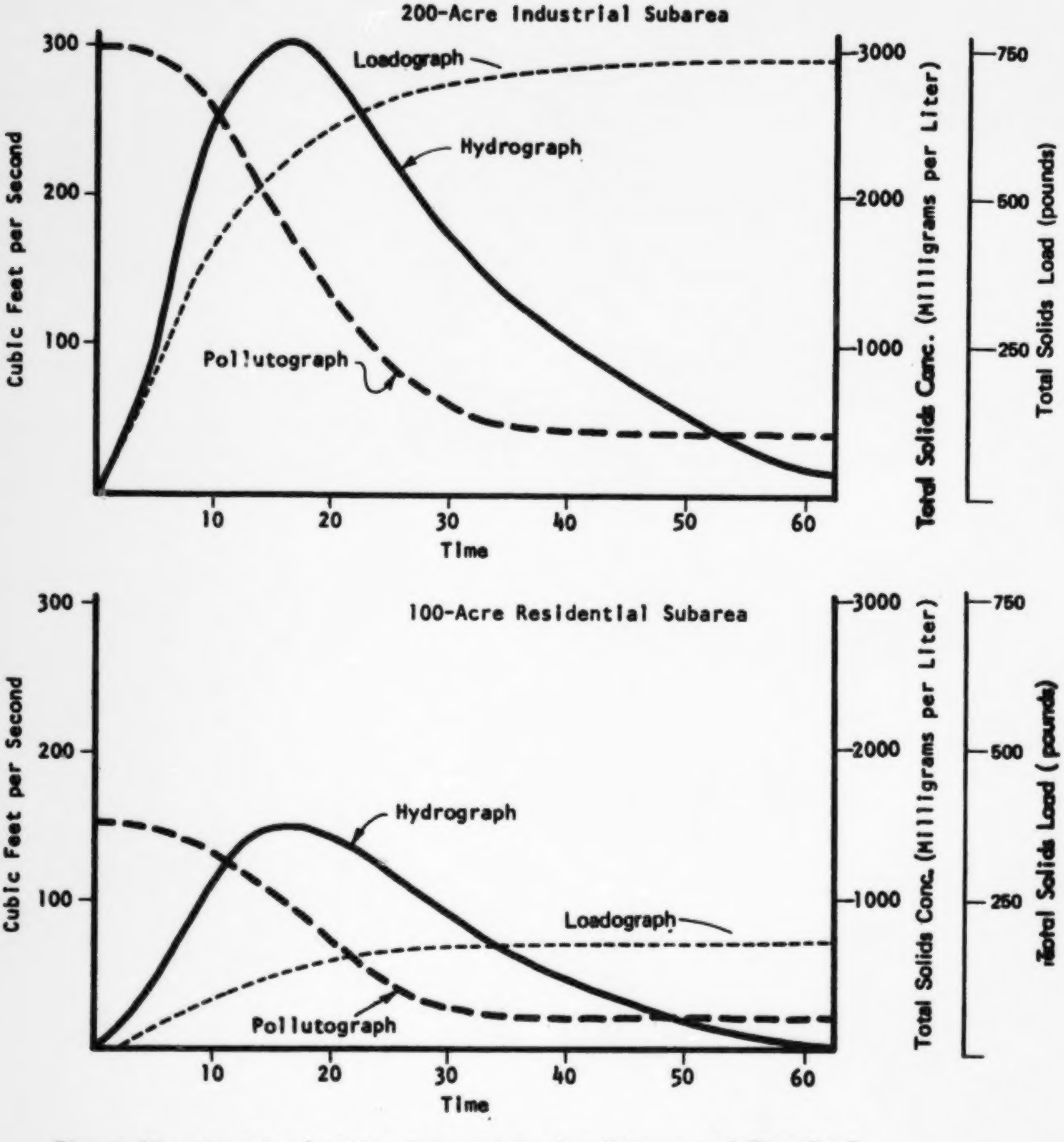


Figure 25. Quantity/Quality Hydrographs for Subareas of Example 8

subarea 1 at time $t - \Delta t_1$ and the flow and quality of subarea 2 at time $t - \Delta t_2$ into the equations. For example:

@ time $t = 15$

$$F_{D,t=15} = F_{1,t=6.5} + F_{2,t=10} = 160 + 130 = \underline{290\ \text{cfs}}$$

$$Q_{D,t=15} = \frac{(F_{1,t=6.5})\ (Q_{1,t=6.5}) + (F_{2,t=10})\ (Q_{2,t=10})}{(F_{1,t=6.5}) + (F_{2,t=10})}$$

$$Q_{D,t=15} = \frac{(160)\ (2800) + (130)\ (1300)}{(160) + (130)} = \underline{2130\ \text{mg}/\ell}$$

$$L_{D,t=15} = L_{1,t=6.5} + L_{2,t=10} = 250 + 88 = \underline{338\ \text{lb}}$$

In a similar manner, other values for the composite flow, pollutant concentration, and pollutant load can be ascertained:

t	$F_{1,t-8.5}$	$Q_{1,t-8.5}$	$L_{1,t-8.5}$	$F_{2,t-5}$	$Q_{2,t-5}$	$L_{2,t-5}$	$F_{D,t}$	$Q_{D,t}$	$L_{D,t}$
5	0	0	0	0	1,500	0	0	0	0
15	160	2,800	250	130	1,300	88	290	2,130	338
25	300	1,700	535	140	750	155	440	1,400	690
35	200	750	665	90	280	185	290	600	825
45	120	440	700	65	200	187	185	360	887
55	70	400	720	30	200	189	100	340	909
65	25	400	730	10	200	190	35	340	920
75	10	400	735	0	200	191	10	400	926

The values of $F_{D,t}$, $Q_{D,t}$, and $L_{D,t}$ are plotted against time to yield the composite quantity/quality hydrograph representing the entire study area as shown in Figure 26.

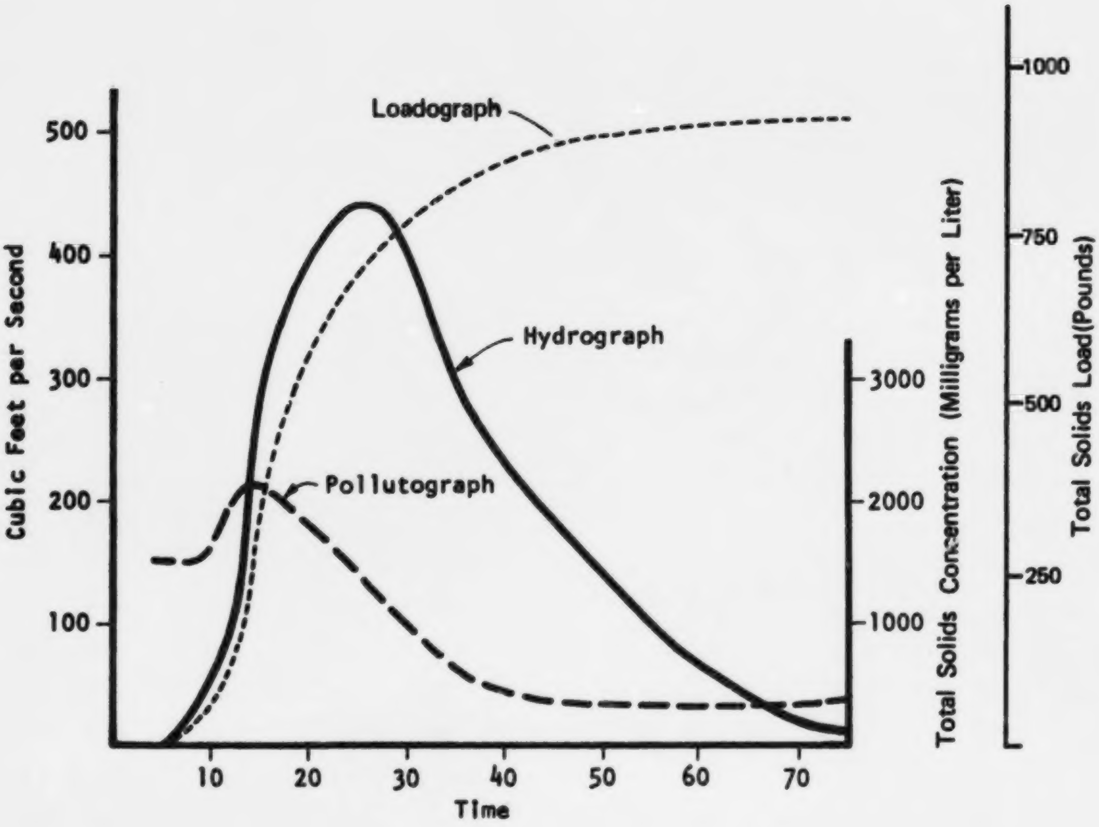


Figure 26. Composite Quantity/Quality Hydrograph of Example 8

EXAMPLE 9

An urban watershed consists of 1,500 acres of impervious surface and 1,000 acres of pervious surface with lawns and sandy soils. The watershed is characterized by a steep slope and has an average contaminant loading of 300 lb/curb mile. A rainfall with an intensity of 0.32 in./hr occurs for 60 minutes. What is the average total solids concentration of the resulting runoff? What is the total load of solids removed by the specified storm event?

Again using the impervious surfaces only,

$$k_{imp} = 0.90$$

$$R = kP$$

$$R = 0.90\ (0.32\ \text{in./hr}) = 0.288\ \text{in./hr}$$

From Table 9, it can be seen that a runoff rate of 0.288 in./hr which lasts for 60 minutes will remove about 73 percent of the residing urban land contaminants.

Volume of Runoff = Runoff Rate X Runoff Duration X Area X 3,630

Volume of Runoff = (0.288 in./hr) (1.0 hr) (1,500 acres) (3,630)

Volume of Runoff = 1,568,160 cu ft

Amt. of Contaminant Removal = Contaminant Load X Area X (% Removal/100)

Assume 600 curb miles in the watershed --

Amt. of Contaminant Removal = (300 lb/curb mile) (600) (0.73)

Amt. of Contaminant Removal = 131,400 lb

$$\text{Concentration} = \frac{\text{Amt. of Contaminant Removal}}{\text{Volume of Runoff}} \times 16{,}019$$

$$\text{Concentration} = \frac{131{,}400 \text{ lb}}{1{,}568{,}160 \text{ cu ft}} \times 16{,}019$$

$$\text{Concentration} = 1{,}342.3 \text{ mg}/\ell$$

Therefore, the average total solids concentration of runoff is 1,342.9 mg/ℓ while the total load of solids washed from streets is about 131,400 pounds.

EXAMPLE 10

It is proposed that a small artificial lake be created to store stormwater runoff for subsequent treatment in an existing sewage treatment plant. A 1-year storm of 30 minutes duration shall be the criteria for design purposes. Stormwater runoff with a concentration of greater than 30 mg/ℓ of BOD will be stored, while runoff containing less than this concentration will be directly discharged into receiving waters. What volume of water should the artificial lake be capable of accommodating?

The study area is located in Dallas, Texas and consists of 2.5 sq mi of a generally flat urban watershed with an average imperviousness of 60 percent. The impervious portions of the study area consist of street surfaces, parking lots, roofs, and others. The average contaminant loading is 400 lb/curb mile with a BOD composition of 30,000 milligrams per kilogram. Forty percent of the total area is occupied by street surfaces, consisting of some 150 miles of streets. Assume L = 15,000 ft and S = .025. The techniques of Level II are used in the following assessment.

Determination of Runoff Rate

The selected storm event will be a 1-year storm of 30 minutes duration. Accordingly, the resultant runoff can be determined as follows:

$k_{imp} = 0.85$

$R = kP$

$P = 1.0$ in./0.5 hr from Figure 4

$R = (0.85)\ (1.0 \text{ in.}/0.5 \text{ hr}) = 1.70 \text{ in./hr}$

Therefore, the selected storm will result in a runoff rate of 1.70 in./hr and a runoff duration of 30 minutes, neglecting the runoff from pervious areas as usual.

Development of Hydrograph

Unit hydrographs for the study area can be developed by utilizing Espey's equations, which may be solved graphically with the assistance of Figures 7 thru 11.

From Figures 7 thru 11:

$L = 15{,}000$ ft

$I = 100\%$

$S = .025$

Hydrograph Characteristics from Total Impervious Area

T_R = 34 min.

Q = 1,100 cu ft/sec

T_B = 210 min.

W_{50} = 48 min.

W_{75} = 31 min.

Hydrograph from street surface runoff will have the same above characteristics except

$$Q = 736 \text{ cfs}$$

The resultant unit hydrographs are shown in Figure 27.

The unit hydrograph must be modified to reflect the selected runoff rate and duration. The unit hydrograph reflects a runoff rate of 2 in./hr and a runoff duration of 30 min, while the selected runoff rate and duration are 1.70 in./hr and 30 minutes, respectively.

The duration of the unit hydrograph and the selected runoff duration are identical; therefore, no modification of runoff duration is required. However, the unit hydrograph is modified to reflect the selected runoff rate by multiplying the ordinates of the unit hydrograph by:

$$\frac{\text{Selected Runoff Rate}}{2 \text{ in./hr}} = \frac{1.70 \text{ in./hr}}{2 \text{ in./hr}} = 0.85$$

The resultant hydrograph, modified to reflect the selected runoff rate, is shown in Figure 28.

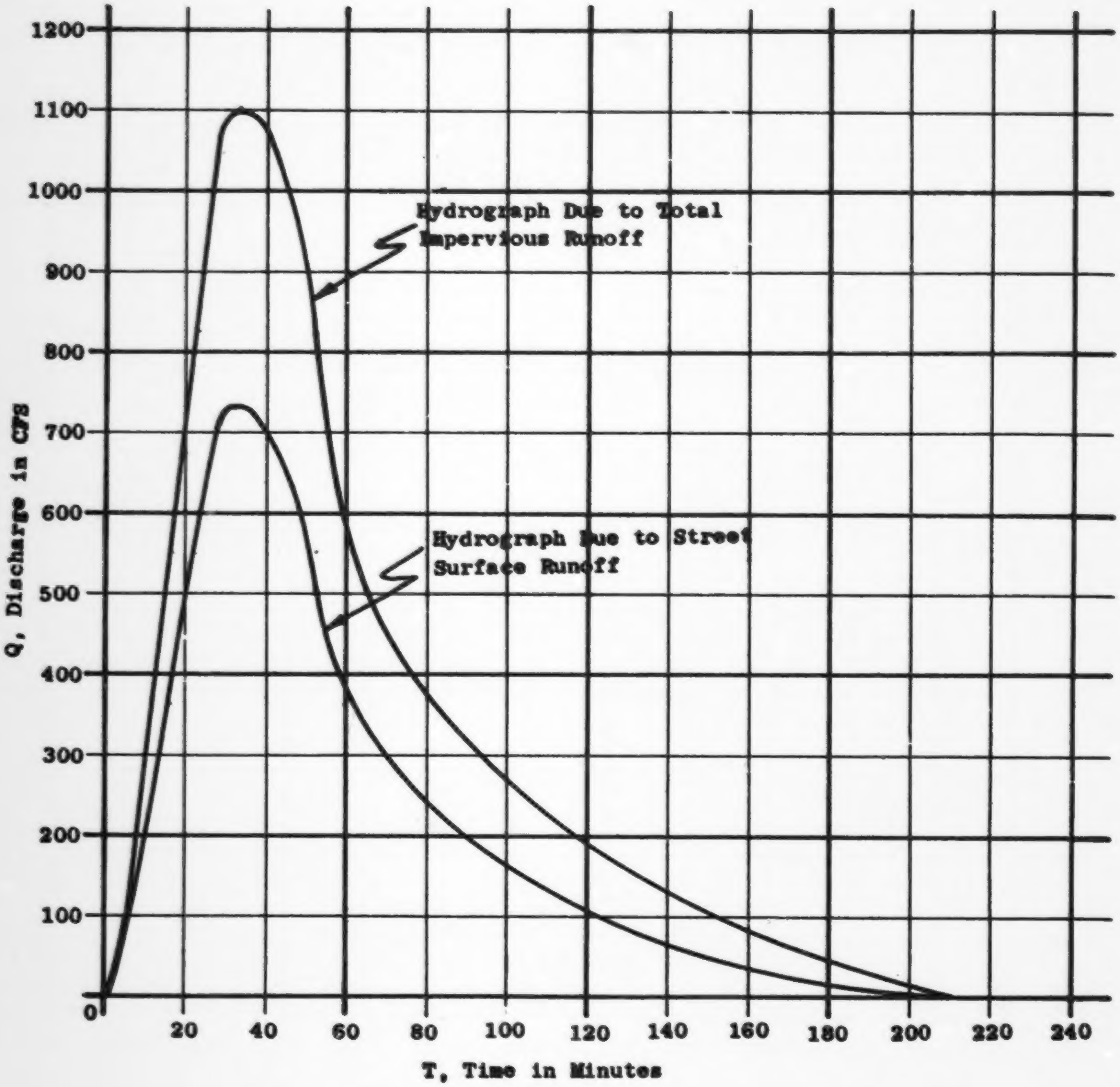


Figure 27. Unit Hydrographs Developed in Example 10.

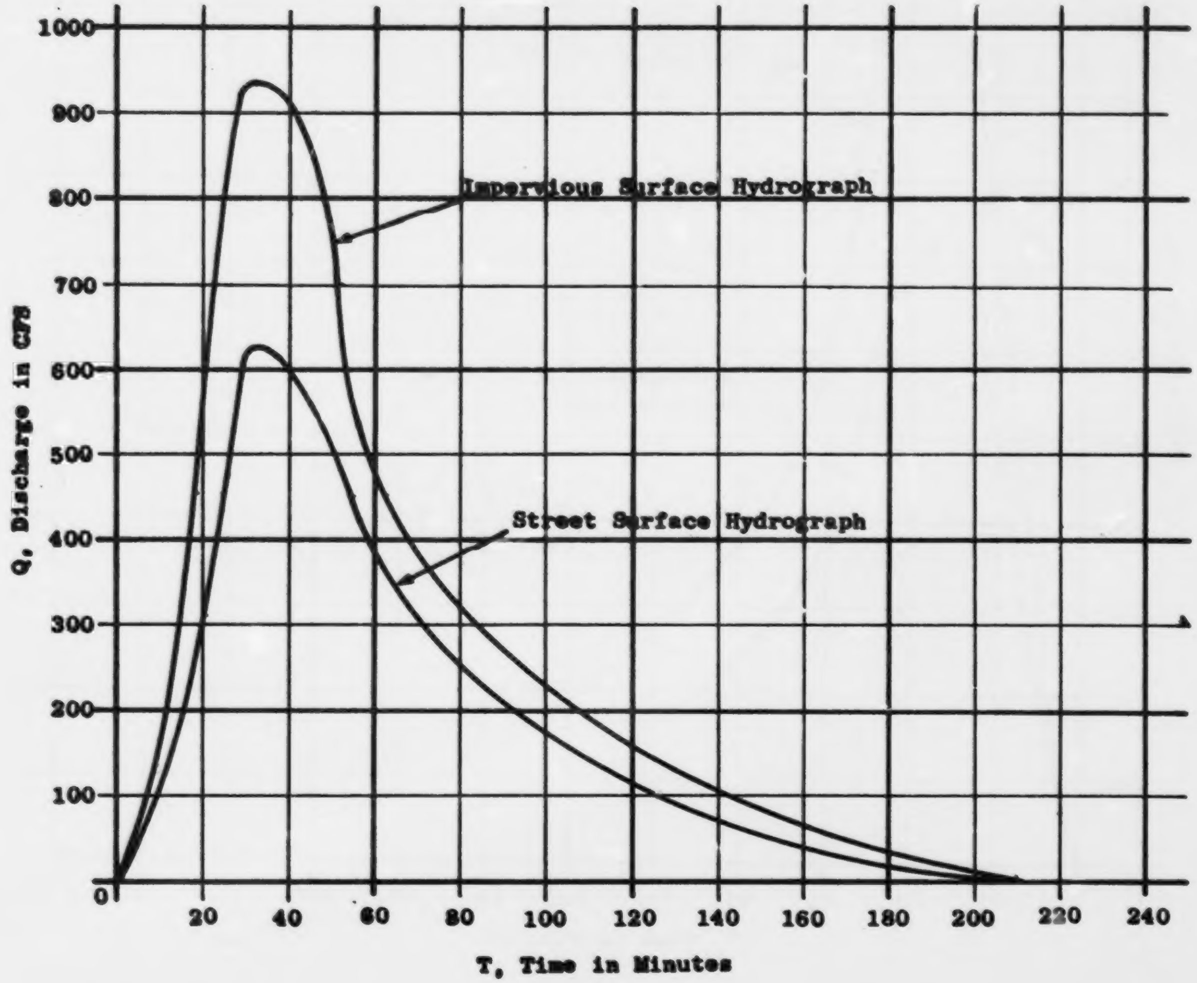


Figure 28. Hydrographs Developed in Example 10

Development of Pollutograph

Using the previously developed hydrograph (Figure 28), the corresponding pollutograph and loadograph will be developed, based on a contaminant loading of 400 lb/curb mile. The pollutograph and loadograph will be developed in a manner similar to that portrayed in Example 7.

$$P_o = 400 \times 150 \times 2 = 120{,}000 \text{ lb.}$$

Values of concentration and load are plotted against time, and the resultant pollutograph and loadograph are shown in Figure 29.

Quantity/Quality Hydrograph

The developed hydrographs (Figure 28), pollutograph and loadograph (Figure 29) are superimposed as shown in Figure 30 to yield the quantity/quality hydrograph which represents the study area under the specified conditions.

Ordinates which portray the concentration and load of BOD are also included in Figure 30. These ordinates were developed by applying the BOD composition data as a proportionality factor to the total solids and ordinates. Since the composition of BOD within the solids is 30,000 mg/kg or .03 kg/kg, values of BOD will be equal to .03 times corresponding values of total solids.

From Figure 30, it can be seen that the resultant runoff will contain less than 30 mg/ℓ of BOD at a time approximately 30 minutes after runoff originates. The total load of BOD removed during this time period is about 2,700 pounds. The runoff volume which occurs from the start of runoff to a time 30 minutes after runoff originates is equal to the area under the hydrograph curve from time = 0 to time = 30 minutes. The runoff volume is graphically estimated to be about 500,000 cu ft, or 11.48 acre-feet, which represents the volume of water that the artificial lake should be capable of accommodating.

EXAMPLE 10

POLLUTOGRAPH AND LOADOGRAPH COMPUTATION

Δt (min)	STREET SURFACE RUNOFF VOLUME (cu ft)	STREET SURFACE RUNOFF r_{avg} (in./hr)	P_o (lb)	ΔP (lb)	$\Sigma\Delta P$ (lb)	TOTAL IMPERVIOUS VOLUME (cu ft)	TOTAL SOLIDS CONCENTRATION (mg/ℓ)	BOD CONCENTRATION (mg/ℓ)
0-10	30,000	0.077	120,000	7,084	7,084	45,000	2,522	75.7
10-20	140,000	0.362	112,916	31,338	38,422	210,000	2,390	71.7
20-30	320,000	0.826	81,578	51,661	90,083	480,000	1,724	51.7
30-40	375,000	0.968	29,917	22,203	112,286	560,000	635	19.1
40-50	315,000	0.814	7,714	4,814	117,100	470,000	164	4.9
50-60	254,000	0.660	2,900	1,467	118,567	380,000	62	1.9
60-70	174,000	0.449	1,433	493	119,060	260,000	30	0.9
70-80	140,000	0.362	940	261	119,321	210,000	20	0.6
80-90	114,000	0.294	679	153	119,474	170,000	14.4	0.4
90-100	94,000	0.243	526	98	119,572	140,000	11.2	0.3
100-110	84,000	0.217	428	71	119,643	125,000	9.1	0.3
110-120	70,000	0.181	357	50	119,693	105,000	7.6	0.3
120-130	58,000	0.150	307	35	119,728	87,000	6.4	0.2
130-140	45,000	0.116	272	24	119,752	70,000	5.5	0.2
140-150	35,000	0.090	248	17	119,769	54,000	5.0	0.15
150-160	32,000	0.083	231	15	119,784	48,000	5.0	0.15
160-170	24,000	0.062	216	10	119,794	36,000	4.4	0.1
170-180	18,000	0.046	206	7	119,801	27,000	4.2	0.1
180-190	13,000	0.034	199	5	119,806	20,000	4.0	0.1
190-200	8,000	0.021	194	3	119,809	12,000	4.0	0.1
200-210	3,000	0.008	191	1	119,810	5,000	3.2	0.1

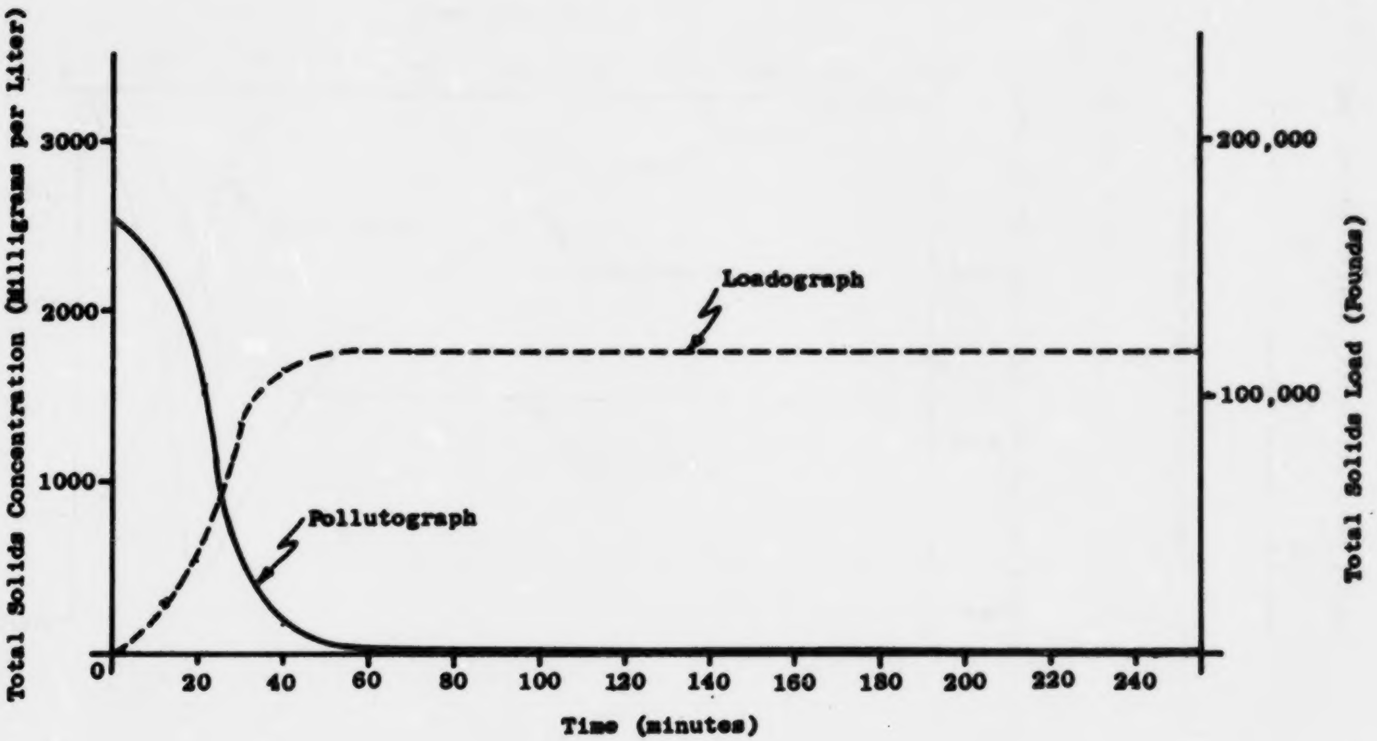


Figure 29. Pollutograph and Loadograph Developed in Example 10

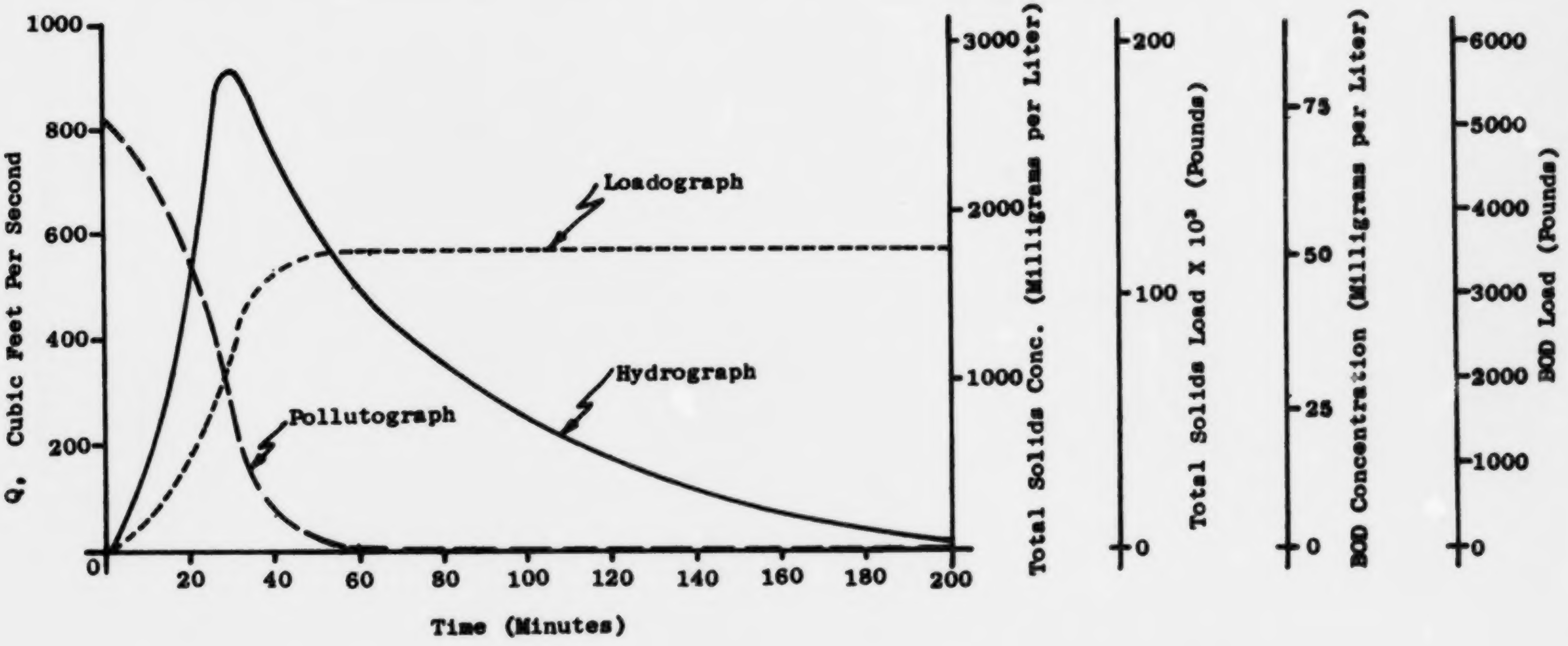


Figure 30. Quantity/Quality Hydrograph Developed in Example 10

Section III

MISCELLANEOUS SOURCES OF URBAN RUNOFF POLLUTION

Section III

MISCELLANEOUS SOURCES OF URBAN RUNOFF POLLUTION

Beyond the major source of urban runoff (i.e., stormwater drainage), there exist several additional sources of pollution which have not been discussed. These sources include: urban irrigation, cleaning, and snow removal. However, of these three sources, only snow removal through the use of deicing compounds has been found to have a significant impact on urban water quality. Irrigation (i.e., lawn watering, etc.) and cleaning (i.e., washing of cars and driveways) have negligible effects because of the very small size of their inputs when compared with other sources of runoff. Snow removal, particularly in the northern snow-belt states, presents a somewhat larger source of both runoff and additional pollutants in the form of deicing salts and their additives.

The current amount of deicing compounds used in the United States has been placed at 9 to 10 million tons of sodium chloride, 0.3 million tons of calcium chloride, and 11 million tons of abrasives. This use is predominately in the eastern and north central sectors of the country with 90 percent of all chloride deicers being used in these areas. The leading states in total use are Pennsylvania, Ohio, New York, Michigan, and Minnesota.[1] With average salting rates usually in the range of 400 to 1200 lb/mi/application,[2] it is not hard to see why they might add to the sodium chloride levels in adjacent receiving waters. In addition to the amounts applied to roadway surfaces, salt storage depots, which are necessary to sustain highway deicing operations, often become a major contributing source of groundwater and surface water salt contamination.

The pollutant loading on local treatment plants and/or nearby receiving streams due to these operations is of such a magnitude as to become significant in locales where deicing occurs on a large scale. In Milwaukee, the daily chloride loads (in municipal sewage) were shown to be 40 to 50 percent higher for winter months as compared with summer months. During times of heavy snow melt, these loads were threefold the normal summertime loads.[2] Indeed, recent studies have shown that 600 lb of salt, when applied to a one-mile section of roadway 20-ft wide containing 0.2 in. of ice, will produce an initial salt solution of 69,000 to 200,000 mg/ℓ in a temperature range of 10°F to 25°F. Analyses of accumulated snow and ice deposits have likewise shown them to contain up to 10,000 mg/ℓ sodium chloride, 100 mg/ℓ oils, and 100 mg/ℓ lead.[2]

In addition to salt contamination, numerous special additives found in present day deicers may create pollution problems more severe than those caused by chloride salts. Sodium ferrocyanide, used to minimize salt caking, is quite soluble in water and will generate cyanide in sunlight. Tests have shown that a 15.5-mg/ℓ solution of this additive produced 3.8 mg/ℓ of cyanide in 30 min (the USPHS standard for cyanide in drinking water is 0.01 mg/ℓ).[2] Chromate and phosphate additives, used as corrosion inhibitors, have also been found in high quantities. A study of snow-melt collections conducted in the Minneapolis-St. Paul area showed values of up to 1.7 mg/ℓ hexavalent chromium (the USPHS standard is 0.05 mg/ℓ).[2]

The effects of these loadings, while not completely known, is becoming relatively well recognized. The most noticeable effect of deicing salts is the frequent damage to roadside soils, vegetation, and trees. Such drainage can take the form of leaf scorch, defoliation, stunting, and ultimately, plant die-off. However, in regards to man's use of water, the main effect of deicing salts is an objectionable taste. While excessive salts can be harmful, health hazards seem relatively rare. Serious groundwater pollution has, however, occurred in many locations. In New Hampshire, more than 200 roadside wells have been replaced at a cost of $200,000 due to salt contamination resulting from highway deicing and leaching from salt storage piles. Some of these wells had chloride concentrations exceeding 3500 mg/ℓ.[2] The USPHS standard for chloride is 250 mg/ℓ. A survey of northern states showed a total of 13 reporting injury to plants, while 12 reported water contamination as side effects from the use of salts.[3] Without some adoption of measures to mitigate these results, the continued intensive use of deicing salts will continue to cause severe plant injuries and additive water pollution effects.

Many techniques and measures can be adapted to each specific locale which can alleviate some of these problems, especially in the area of salt storage depots. Because this problem is beyond the scope of this study, we recommend that the reader consult the EPA study on the "Environmental Impact of Highway Deicing"[1] to obtain the necessary information.

REFERENCES

1. Field, R., et al., "Water Pollution and Associated Effects of Street Salting," National Environmental Research Center, EPA (May 1973).

2. "Environmental Impact of Highway Deicing," 11040 GKK 06/71 Storm and Combined Sewer Technology Branch, Edison Water Quality Research Laboratory, EPA (June 1971).

3. Hanes, R. E., et al., "Effects of Deicing Salts on Water Quality and Biota -- Literature Review and Recommended Research," National Cooperative Highway Research Program Report 91, Virginia Polytechnic Institute and Highway Research Board (1970).

Section IV

TREATMENT, ABATEMENT, AND DISPOSAL OF URBAN RUNOFF

Section IV

TREATMENT, ABATEMENT, AND DISPOSAL OF URBAN RUNOFF

A. EVALUATION OF URBAN RUNOFF QUALITY

In order to determine the significance of non-point water pollution originating from an urban study area, the user must evaluate the results of his assessment of urban runoff conducted in Section I. Theoretically, this evaluation should consist of comparing predicted pollutant concentrations and loads against local, state, and federal water quality standards. Unfortunately, standards which are directly applicable to the discharge of urban storm water runoff into receiving waters are still in the developmental stage and therefore, have not been established.

Consequently, the user may substitute standards which are applicable to effluent discharges from point sources (i.e., sewage treatment plants, industrial sources, etc.). Alternatively, the user may supply his own criteria for evaluation until applicable standards are enacted. Such criteria could be based upon the ambient water quality and pollutant assimilation characteristics of a particular receiving water.

Based upon the evaluation, the user can determine if treatment, abatement, or an alternative method of disposal is required. The following material is intended to provide a basic insight into the alternatives regarding treatment, abatement, and disposal of urban runoff. It is not intended to serve as design criteria nor as an absolute source of information on the subject.

B. SOURCE ABATEMENT

Although the accumulation of a certain amount of street surface contaminants in an urban environment is inevitable (e.g., pavement wear, dirt, grease and oil from the undersides of motor vehicles), much of the litter that reaches the street surface can be eliminated, or at least effectively controlled at its source. This direct approach to reducing the runoff pollution potential can best be accomplished through active public education and through effective and enforceable regulations and ordinances relating to street cleanliness.

In order to gain public support and cooperation in reducing street litter, an effective education program is necessary to inform the public of all the ramifications of street litter, including its effect on water pollution. This information can be presented in well-organized school programs; press, radio, and television messages; and lectures to local civic organizations. A list of regulations and ordinances, possibly in leaflet form, that pertain to litter control should be available so that all citizens may understand what is expected of them. This list or digest should be printed in all appropriate languages of the community.

The local government can do its part by providing an adequate number and variety of litter containers and by setting a good example. Litter containers should be kept in a presentable condition and should be emptied frequently. Strict cleanliness practices should be followed by city waste collection forces and other city departments which generate litter. Street sweeping and sanitation equipment should be kept in attractive condition to encourage community pride and respect.

Well-publicized cleanup campaigns can also provide motivation for the public to clean up the premises and dispose of accumulated trash. In many cities, spring cleanup days, in which free pickup of bulky refuse is offered by the city, has been very popular. Guidance for the conduct of community cleanup programs can be obtained from Keep America Beautiful, Inc., 99 Park Avenue, New York, NY 10016.

The legal approach to the problem of street surface litter will usually take the form of establishing definitive ordinances describing improper littering practices and prescribing penalties for violation. Those public officials responsible for maintaining clean streets should establish the antilitter ordinances and should be given adequate legal authority to enforce these ordinances. In addition to the general antilitter ordinances, specific regulations should be directed to the following typical sources of litter in the urban environment:

- garbage and refuse collection
- open trucks
- public litter receptacles
- refuse dumping
- building construction and demolition
- street construction
- sidewalk sweeping
- vacant lots
- parking lots and garages
- drive-in restaurants
- trailer courts and campgrounds
- sports stadiums
- auditoriums and exhibition halls
- theaters
- food handling establishments
- pet control

- distribution of handbills
- posting of notices and political posters
- street vending
- garden refuse
- scavengers
- weed control
- dead animals
- produce markets
- direct discharges into storm sewers

Typical and model antilitter ordinances published by Keep America Beautiful, Inc. and by AWPA in its book "Street Cleaning Practices" may be used as check lists to determine the adequacy of existing local ordinances and to establish new litter control ordinances.

The effectiveness of local ordinances will depend on the enforcement. Enforcement can often best be accomplished through municipal interdepartmental cooperation. For example, the police department could enforce ordinances pertaining to littering from moving vehicles, illegal dumping of refuse, the storage of construction materials on sidewalks and streets, etc. The fire department could enforce regulations pertaining to storage of refuse which might create a fire hazard. The health department could be concerned with the handling and storage of refuse by food-handling establishments. Other city departments could enforce regulations related to their functions. Enforcement by these agencies should include both inspections and summonses.

An important aspect of litter ordinances and regulations is to establish the responsibility for each source of litter. In many circumstances it is impossible or impracticable to catch persons who actually do the littering, but more responsibility could be placed on the owner of the property where the litter occurs. This approach is common in many European towns, where each storeowner or homeowner is responsible for maintaining the sidewalk and curb fronting his property.

A major problem of litter control in most of the larger cities is parked or abandoned cars. Parked cars make it impossible for street cleaning equipment to clean all of the street. Part of this problem can be solved by parking regulations which prohibit parking in certain areas during specific hours. In residential areas, these parking restrictions may apply only once or twice a week, while in commercial areas they may apply every day.

The problem of abandoned cars is much more difficult to control, particularly in the very large cities. Abandoned autos not only interfere with street cleaning operations but are a source of street litter. Abandoned autos should be removed from the streets as soon as possible, either by city forces or by a private contractor hired by the city. The sale or auction of operative vehicles, and possibly the sale of parts from a city-owned and operated junk yard, could help defer the cost of removal.

Regulations should also be established that limit the use of chemicals commonly used in the urban environment for weed and pest control. Since the city is usually responsible for the use of large amounts of these chemicals, regulations should be relatively easy to enforce.

C. TECHNICAL ABATEMENT

1. Improved Street Cleaning Practices

Street surface contaminants, which represent a major portion of urban land contaminants, can be partially removed by street sweeping operations prior to being exposed to runoff. A primary method of abating urban runoff pollution is to improve existing street cleaning practices.

Municipal street cleaning practices may be improved by (1) increasing the frequency of street sweeping and/or (2) increasing the removal effectiveness of street cleaning methods.

Motorized street sweepers are designed to loosen dirt and debris from street surfaces, transport it onto a moving conveyor, and deposit it temporarily in a storage hopper. The three major types of street sweepers include the broom-type sweeper, the vacuum-type sweeper, and a third type of sweeper which uses a regenerative air system to "blast" dirt and debris from the road surface into a hopper.

Municipal street sweepers typically remove about half of the contaminants residing on street surfaces. The efficiency of contaminant removal is related to the particle size distribution of the contaminant material. Sweepers are most efficient in removing large size particles while most pollutants are predominantly found in the small particle size range of contaminant material. Street sweeper efficiency as a function of particle size is described in Table 12.

Table 12. AVERAGE STREET SWEEPER REMOVAL EFFICIENCY

Particle Size (μ)	Percent Removal
<104	17
104 - 246	48
246 - 495	55
>495	67

Street surface contaminant accumulation is a function of street sweeping frequency, street sweeping removal effectiveness, and antecedent rainfall events. The accumulation of street surface contaminants can be minimized by increasing the frequency of street sweeping operations. Commercial areas are generally swept more often than other land use areas, which explains the lower contaminant loadings found in commercial areas.

The removal effectiveness of street sweeping operations can be improved by sweeping an area more than once. Repeated passes over the same area can effectively reduce the amount of contaminant material remaining on a street surface. Figure 31 shows typical removal effectiveness vs the number of passes of a street sweeper, based on a surface loading of 10 g/ft^2.

The practice of repeated sweeping passes over the same area and the practice of increased street sweeping frequency are essentially mutually exclusive. Since there is only a finite number of available street sweeping vehicles, an increased utilization of one practice will result in a decreased utilization of the other. This phenomenon can be partially circumvented by the acquisition of additional street sweeping vehicles.

Besides increasing the sweeper frequency, street pollutant removal may be improved by more efficient use of existing equipment and practices. Table 13 shows some common parameters that affect street sweeping performance. Figures 32 through 35 show how some of these parameters affect removal effectiveness.

Vacuum-type sweepers have shown promise in achieving a fairly high removal effectiveness, including the small particle size range of contaminant material, but their effectiveness falls off dramatically if the streets are wet. On the contrary, broom-type street sweepers are especially prone to difficulty in removing small particle sizes.

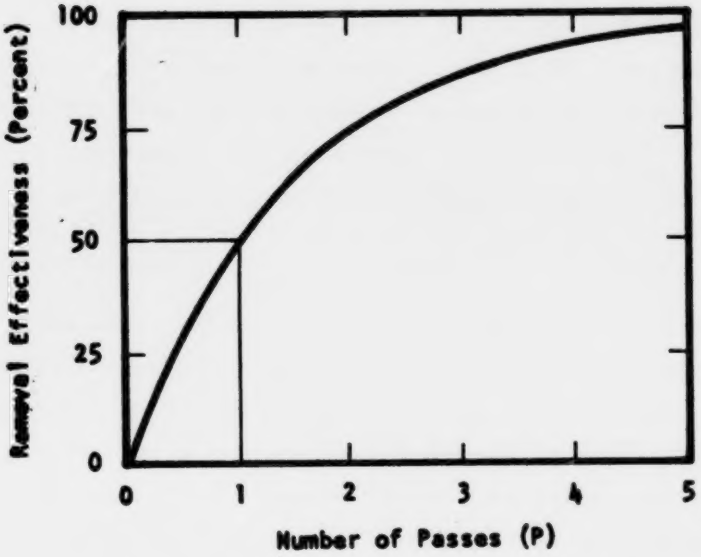


Figure 31. Removal Effectiveness With Number of Passes

Table 13. PARAMETERS WHICH AFFECT STREET SWEEPING PERFORMANCE

Fixed	Loading:	Mass level
		Particle size
		Uniformity
	Surface:	Type
		Condition
	Sweeper:	Type
Controllable	Sweeper operation:	PUB[a] type
		PUB rpm
		PUB diameter
		PUB strike
		Forward speed
		Number of passes
		Gutter broom
		Debris deflector
Untested	Operator skill	

a. PUB - Main Pickup Broom

From Figure 35, one can see that a flusher removes more materials per "unit effort" than a sweeper. It must be remembered that a flusher does not remove the contaminants from the receiving water system, but actually discharges the pollutants during periods of no rainfall.

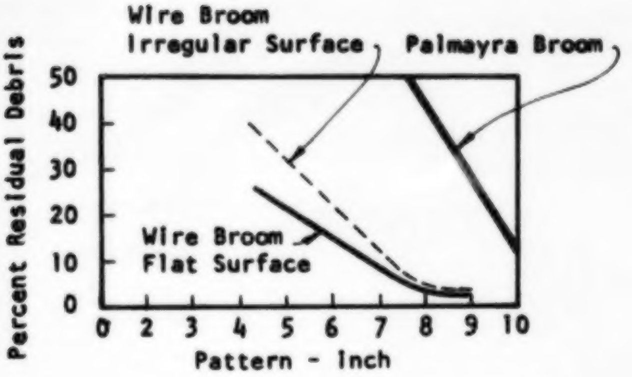


Figure 32. The Effect of Pattern on Residual Debris

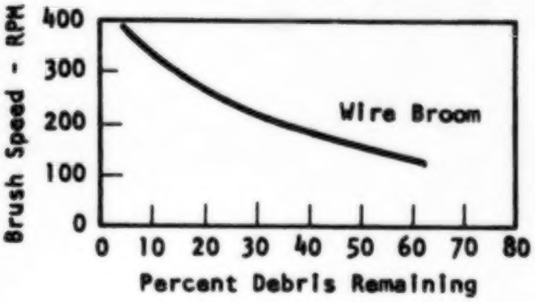


Figure 33. Debris Pickup vs Brush Sweeper

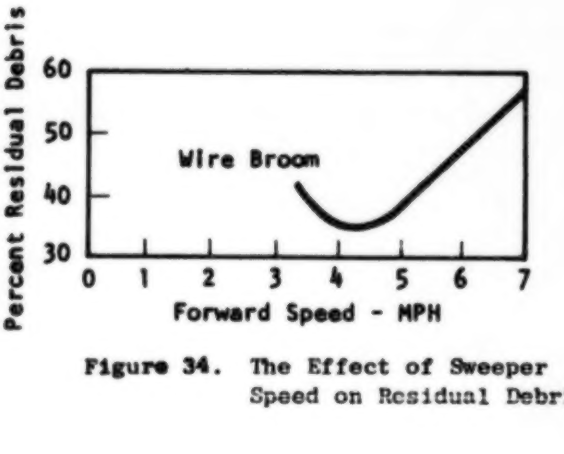


Figure 34. The Effect of Sweeper Speed on Residual Debris

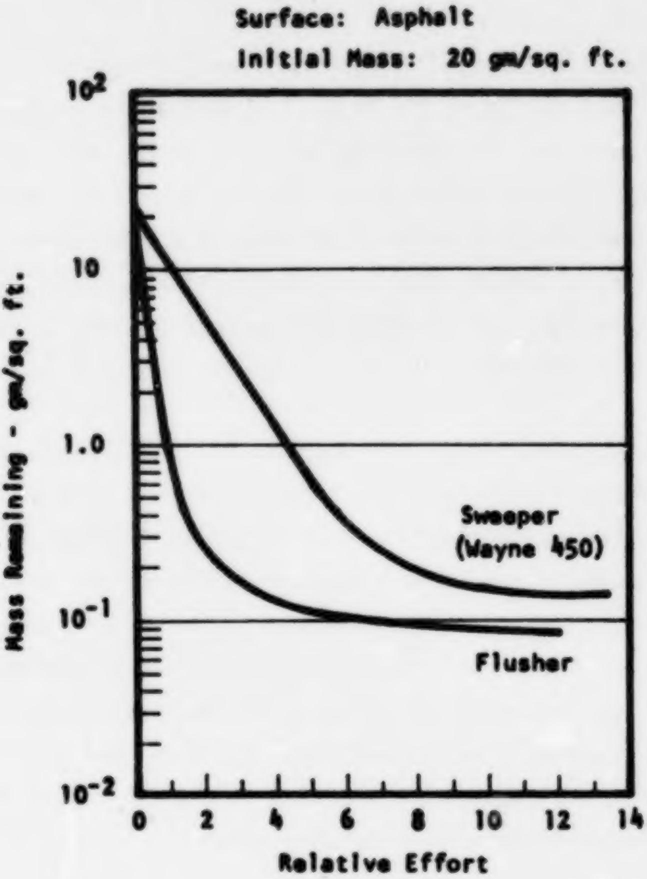


Figure 35. Comparison of Cleaning Performances of Motorized Street Sweeping and Motorized Street Flushing

2. Air Pollution Controls

Atmospheric dustfall can be a noticeable source of particulate contaminants that are washed off surfaces during rainfall events. Dustfall results from the deposition of particulate matter from the atmosphere.

Some of this particulate material occurs naturally (fugitive dust from soils and pollens) and is difficult if not impossible to control. Other particulate material is caused by man-made processes. These include fugitive dust from disturbed soils (during and after construction) and stockpiles; emissions from combusting materials, and emissions from chemical reactions and grinding and pulverizing operations. Smoke, made up of fine particles, is the most obvious particulate pollutant associated with human activity.

Recent advances in stationary source controls for particulate matter have resulted in removal efficiencies commonly greater than 99 percent. Emissions from stationary sources are controlled by a large variety of local, state, and federal agencies. These regulations are designed to prohibit the accumulation of harmful concentrations and to prohibit nuisance conditions. These particulate emissions can be controlled by a variety of devices, including settling chambers, centrifugal separators, inertial separators, liquid scrubbers, filters, and electrostatic precipitators. The applications of specific devices for specific emissions are best determined by a case-by-case study.

Particulate emissions from mobile sources are small per emission device; but due to the large number of devices, their contribution can be severe. Table 14 shows the breakdown of nationwide particulate emissions for 1970.

Table 14. NATIONWIDE ESTIMATES OF PARTICULATE EMISSIONS, 1970

Source category	Emissions, 10^6 tons/year	Percent of total
Transportation	0.7	2.7
Motor vehicles	0.4	1.5
Gasoline	0.3	1.1
Diesel	0.1	0.4
Aircraft	0.1	0.4
Railroads	Neg[a]	-
Vessels	0.1	0.4
Nonhighway use of motor fuels	0.1	0.4
Fuel combustion in stationary sources	6.8	26.1
Coal	5.6	21.5
Fuel oil	0.4	1.5
Natural gas	0.2	0.8
Wood	0.6	2.3
Industrial process losses	13.3	51.0
Solid waste disposal	1.4	5.3
Agricultural burning	2.4	9.2
Miscellaneous	1.5	5.7
Forest fires[b]	1.4	5.3
Structural fires	Neg	-
Coal refuse burning	0.1	0.4
Total	26.1	

[a] Negligible (less than 0.05 x 10^6 tons/year).
[b] Includes prescribed burning.

Source: EPA: Nationwide Air Pollutant Emission Trends, 1940-1970.

The emissions from mobile sources are controlled by state and federal agencies. The EPA has not proposed any particulate emission controls for automobiles, but has for other types of vehicles (heavy duty, aircraft, vessels, etc.).

D. TREATMENT

The treatment of urban stormwater runoff has been approached in two major ways over the past several years. One approach has seen the development of varied means of storing the peak flows and discharging them to conventional treatment plants during low flow periods. These peak flows would normally be discharged untreated. The second approach, which can be used in conjunction with storage, has seen the development of specialized treatment processes to deal specifically with quantities and types of pollutants found in stormwater runoff.

This section briefly outlines some of the common treatment and storage techniques that have been used or show promise. This section is not meant to supply sufficient information to design a complete treatment scheme, but to give the planner a general idea of the methods available and some costs.

1. Storage and Treatment

Although urban stormwater runoff is similar in many respects to raw sanitary sewage and is amenable to many of the same treatment processes, certain aspects of runoff create unique treatment problems. The main problems encountered in treating urban runoff include (1) the intermittent and random occurrence of the runoff event with correspondingly high flow rates, and (2) heavy loadings of solids.

Perhaps the most serious problem involved in treating urban runoff is created by high flow rates. The hydraulic capacity of most treatment plants is not sufficient to treat the total flow during high flow rate periods of runoff. To overcome this obstacle, either the flow rate of the runoff water entering the treatment process must be reduced, or the hydraulic capacity of the treatment process must be increased, or the detention time must be decreased. Usually a combination of those approaches is the most desirable solution.

The following discussion on storage and treatment of stormwater runoff is abstracted primarily from a recently completed EPA state-of-the art document entitled, Urban Stormwater Management and Technology: An Assessment, 1973.

a. Flow Rate Control

Several methods have been proposed for controlling the flow rate of runoff waters into treatment facilities. The following is a brief description of these various methods, including the advantages and disadvantages of each and construction and maintenance cost estimates where available.

b. Storage Facilities

One of the most effective methods of controlling the flow rate entering the treatment plant is to store the runoff during peak flows and discharge it to the treatment facilities at a controlled rate during subsequent low flow periods. Storage is perhaps the most cost-effective method available for managing urban runoff, and it is the best documented stormwater pollution control measure in present practice.

Examples of runoff storage facilities include open ponds, steel and concrete tanks, underground tunnels and caverns, existing sewers, and underwater collapsible tanks.

Advantages of such storage facilities are: (1) they are generally simple to design and operate; (2) they are relatively unaffected by rapid changes in runoff flow rates and quality; (3) they frequently can be operated in concert with existing waste water treatment plants; and (4) they can serve as preliminary sedimentation basins, there reducing the sediment handling requirements of subsequent treatment processes.

Disadvantages of storage facilities include: (1) their large size; (2) their rather high construction costs; (3) the problem of removing solids that have settled out; and (4) their dependence on other treatment facilities for final treatment of the retained water.

c. Open Ponds - The surface storage pond is by far the most frequently proposed method of runoff storage. Varieties range from simple earthen dams to concrete or asphalt lined basins.

An asphalt lined detention basin with a storage volume of 8.66 acre feet was built as an EPA demonstration model in Chippewa Falls in 1969. Although the basin was built to receive overflow from a combined sewer system, the same principles of operation apply to the detention of flows from separate storm sewers. Captial costs for the project, including the required additions to the capacity of the municipal treatment plant which finally treated the detained water, were $6780 per acre of drainage area. Operation and maintenance costs for the pond and associated facilities during the two-year test period (1969 and 1970) were $7300 per year.

An example of a multiple use detention basin is contained in an apartment development in Arlington Heights, Illinois, where stormwater runoff from the site is temporarily stored in a depressed area that is used as a tennis court during dry weather. The retained runoff is released into the area's drainage system only after the peak flow of the uncontrolled stormwater runoff has occurred.

Such local storm retention ponds should be considered in the planning of storm drainage systems for new communities and in the modification of existing drainage systems. Such ponds will reduce the peak flows of runoff resulting from urbanization. They also can reduce the needed capacity (and thus the costs) of drainage pipes and treatment systems. If storm retention ponds are constructed prior to the develcpment of of an area, they can also provide erosion and sediment control for the area during the construction phase of the development.

d. Storage Tanks - Steel or concrete storage tanks can be used to detain runoff in areas where surface ponds are physically or economically infeasible because of the large land requirements. Although construction costs of tanks are high compared to the costs of surface ponds, tanks do not require the algae and mosquito control measures that are often necessary in open storage facilities; and they can be designed for easier removal and disposal of settled solids.

e. Underground Tunnels - Due to the lack of usable surface area for detention ponds or even storage tanks, underground tunnels or storage caverns are being mined 200 to 300 feet beneath Chicago to provide storage for combined sewer overflows. The underflow-storage tunnels will have a total capacity of 18,000 acre feet. A 2.5-mile-long test tunnel was mined at a cost of $1.5 million.

f. Use of Existing Sewers - With the use of a computerized sewer monitoring and control system, the city of Detroit can utilize existing sewers in the downtown area for runoff storage. A complex array of rainfall and overflow monitors coupled to a central computer can better utilize the existing capacity of the sewers by moving high flows to areas of the system experiencing low flows. The cost of the project has been estimated at $2.2 million.

g. Underwater Storage - A rather unique solution to the problem created by the lack of usable surface area is the use of underwater collapsible tanks. In a pilot program, 100,000-gallon collapsible tanks were anchored offshore from Sandusky, Ohio, in Lake Erie. Stormwater overflows were diverted into the tanks and later pumped ashore for treatment. The project cost was $2 per gallon, but projected future costs were placed at 40 cents per gallon.

The flow rate and runoff influent into treatment facilities can be indirectly controlled by controlling the flow rate entering the city's storm drainage system. An example of this approach to runoff control is given below.

h. Rooftop Ponding - In an 80-acre urban renewal project in downtown Denver, rooftops were constructed to hold up to 3 inches of rainwater. This water was retained then released as surface runoff at a controlled rate. Other rooftop storage schemes use the intercepted rainwater to supplement the water requirements of an industrial complex.

2. Physical Treatment

Various methods of physical treatment are presently available that can effectively be used for the removal of suspended solids from stormwater runoff, but at the present time, physical treatment is generally less effective in the removal of organics and nutrients than biological or physical-chemical treatment.

The major advantage of physical treatment processes is their adapability to automated controls and the rapid startup and shutdown that is often required in runoff treatment. Recent improvements in physical treatment processes have resulted in more rapid removal of suspended solids and more effective removal of organics.

In addition to the conventional physical treatment processes used in wastewater treatment (i.e., sedimentation; flotation; screening, and filtration), more recent physical treatment processes have been developed that promise to be well suited for stormwater runoff treatment. These techniques include dissolved air flotation, ultrahigh rate filtration, swirl concentration, and a variety of screening techniques.

Dissolved air flotation has been shown to be a rapid and rather effective technique for removing solids. In addition, organic removal has been rather high for a physical treatment process. In tests, this process has effectively removed approximately 40 percent of the organics and 60 percent of the solids from a combined sewer overflow under a surface loading rate of 900 cu m/min/ha (3200 gpd/sq ft). The addition of about 25 mg/ℓ of chemical flocculate increased these removal efficiencies by 30 percent. Probably the main drawback of the dissolved air flotation process at the present time is the high cost. Construction costs of $800/ℓ/sec ($35,000/mgd) have been reported. However, a treatment system for combined overflow and separate stormwater runoff in Sacramento, California, which included dissolved air flotation was determined to be the least-cost design. Capital costs for this project were $530,000/ℓ/sec ($12,000/mgd), and operating costs were estimated at $6.87 per 1,000 ℓ ($26/1,000 gal).

a. Screening

A variety of screening techniques have been effective as primary treatment processes. Ultrafine screens, rotary fine screens, and hydraulic sieves are usually used as pretreatment units. The rotary fine screen requires only one-tenth to one-twentieth the land use normally required for primary treatment (sedimentation or flotation). Costs for rotary screening have been reported at 5.8¢ per 1,000 ℓ (22¢/1,000 gal) for a 1,100 ℓ/sec (25 mgd) facility (including debt service).

Ultrafine screens and microstrainers are generally used as main treatment and/or polishing devices in stormwater treatment. These techniques can remove from 10 to 70 percent of the organic material and 25 to 90 percent of the suspended solids in wastewater, depending on the size of the screen, the loading rates, and the character of the wastewater. Although ultrafine screens and microstrainers are rather effective in the removal of suspended solids in stormwater runoff, additional studies are required to better evaluate the efficiency of organic removal. The average capital cost of these screening processes, based on a design flow rate of 17 ℓ/sec/sq m (25 gpm/sq ft) is approximately $297/ℓ/sec ($13,000/mgd).

A study has been begun recently to compare the effectiveness of three screening devices (ultrafine screen, rotary fine screen, and stable screen) operating on combined sewage overflows.

b. High and Ultrahigh Rate Filtration

Effective treatment of combined sewer overflow containing an average of 250 mg/ℓ suspended solids and 67 mg/ℓ BOD was obtained in a treatment plant in Cleveland, Ohio, by adding a polyelectrolyte and then filtering the influent through a deep bed, dual media filter at a rate of 24 gpm/sq ft. This method resulted in a 93 percent reduction of suspended solids and a 61 percent reduction in the BOD. Total annual treatment costs (capital and operating) were estimated at $90,000 for a 25-mgd plant and $390,000 for a 200-mgd plant.

Successful results on a bench scale, have also been obtained from ultrahigh rate filtration of stormwater runoff. Filtration rates up to 30 ℓ/sec/sq m (45 gpm/sq ft) through a dual media filter, following pretreatment through an ultrafine screen, have resulted in suspended solids removal of 38 to 73 percent and organic removals of 8 to 36 percent.

The advantages of these treatment processes are (1) high removal efficiencies, (2) automated operation, and (3) limited space requirements (as opposed to flotation and sedimentation).

c. Swirl Concentrator

Other recent developments in physical treatment processes include a swirl flow regulator/solids separator with no moving parts. This low cost method of solids removal has been thoroughly tested, and prototype demonstration units are being constructed.

3. Biological Treatment

Although biological treatment has been a popular and successful method of treating domestic and industrial waste water, its application to the treatment of stormwater runoff has the following serious drawbacks: (1) the biomass used in the treatment process must be kept alive during nonflow periods or developed for each runoff event; and (2) once developed, the biomass is highly susceptible to washout by hydraulic surges or overload unless flow equalization is maintained.

However, recent developments in biological treatment may have applications to stormwater runoff treatment. Such biological treatment processes include: (1) the contact stabilization of activated sludge; (2) high rate trickling filtration; (3) bioadsorption using rotating biological contactors; and (4) oxidated lagoons of various types. The first three methods must be operated conjunctionally with dry weather flow plants to supply the biomass. Also with the exception of lagoons, some form of pre-unit flow equalization is necessary to prevent the washout of the biomass.

Nearly 92 percent of the suspended solids and 83 percent of the organic matter have been removed from combined sewer flows using the contact stabilization method. Construction costs, excluding land, of the tested project were $1,785/ℓ/sec ($78,300/mgd) of capacity.

a. High Rate Trickling Filters

A high rate trickling filter process has treated flows up to 10 times average dry weather flows. Removal efficiencies for both organic and solids were approximately 65 percent. The cost of required plant additions was \$1,550/ℓ/sec (\$68,000/mgd) of capacity.

4. Physical-Chemical Treatment

Although at the present time construction costs are high, physical-chemical treatment is becoming competitive in cost with biological treatment. Physical-chemical processes are of particular importance to stormwater runoff treatment because of their adaptability to automated operation, rapid startup and shutdown, and very good resistance to shock loads.

Disadvantages of physical-chemical treatment, in addition to the high construction costs, are high chemical requirements and problems of sludge disposal.

In a recently completed pilot study for the EPA, a complete physical-chemical process (comparable to secondary treatment) was developed and tested. This technique, which incorporated chemical clarification followed by adsorption on activated carbon, resulted in removal efficiencies of 94 percent of BOD and 99 percent of suspended solids. It was determined that a 10-mgd facility of this type could be developed at a capital cost of \$1.8 million and an operating cost of 19¢/1,000 gal).

E. ALTERNATE METHODS OF DISPOSAL

1. Spray Irrigation

The beneficial use of stormwater runoff as irrigation water deserves consideration. Nutrients and organic material contained in stormwater runoff are capable of stimulating plant growth. However, the significant concentrations of heavy metals found in stormwater runoff may impair its use as irrigation water.

In certain areas, legal restrictions are placed on the use of sewage treatment effluent as irrigation water for crops intended for direct human consumption. Although these restrictions may also apply to a similar use of stormwater runoff, they do not apply to crops intended for animal consumption.

2. Infiltration Ponds

Stormwater runoff may be discharged into infiltration ponds for the purpose of groundwater recharge. A degree of treatment can be imparted to stormwater runoff which is allowed to percolate through soil. Soil particles are capable of filtering out residue and partially treating stormwater runoff before it reaches the groundwater table.

Section V

STATE OF THE ART

Section V

STATE OF THE ART

An extensive literature review has revealed that the significance of stormwater runoff pollution was not fully appreciated until about the last ten years. Although occasional studies revealing some of the water quality aspects of stormwater runoff were conducted in the 1940s and 1950s, most of the runoff studies during this period dealt with the quantitative aspects of runoff.

The earlier runoff quality studies were usually concerned only with water quality characteristics. This was usually accomplished by collecting and analyzing water samples within the storm sewers or at the outfall. As the significance of the problem became more apparent, studies were directed toward defining and analyzing the sources of runoff pollution; establishing relationships between water pollution parameters and land use, population density, traffic volume, etc.; using these relationships to develop methods or models for predicting the pollution potential of a given area; and suggesting and evaluating pollution control measures.

The following discussion lists some of the more significant and frequently cited studies on urban runoff. This is not a complete list of urban runoff studies; it is only a representative sample to indicate the type of work that has been done in this area. A more inclusive annotated bibliography and a cross-indexed information matrix has been provided in Appendix C for further information or background on particular aspects of urban runoff.

1. Characteristics of Urban Runoff

One of the first published studies on the pollution potential of urban stormwater runoff was conducted in Moscow, U.S.S.R., in 1936.[1] BOD_5 samples taken in this study ranged from 186 to 285 mg/ℓ, while suspended solids ranged from 1000 to 3500 mg/ℓ. Runoff samples taken from Leningrad's cobblestone streets in 1948-1950 contained BOD_5's of 36 mg/ℓ and suspended solids of 14,541 mg/ℓ.[1]

From 1945 to 1948 in Stockholm, Sweden, runoff samples were taken during summer storms.[2] Most of the samples were taken from streets and parks. Test results on these water samples revealed median values of 17 mg/ℓ BOD_5, 188 mg/ℓ COD, 300 mg/ℓ total solids, and 4000/100 mℓ coliforms. Evidence of the potential for shock pollution was revealed by individual samples which ranged as high as 80 mg/ℓ BOD_5, 3100 mg/ℓ COD, 3000 mg/ℓ total solids, and 200,000/100 mℓ for coliforms.

One of the earliest and most often cited studies in this country was conducted by Palmer in downtown Detroit, Michigan, in 1949.[3] Water samples taken at catch basins indicated BOD_5 levels on the order of 96 to 234 mg/ℓ, 310 to 914 mg/ℓ total solids, and coliform counts of 25,000 to 930,000 MPN/100 mℓ.

In 1954, runoff samples taken from a 611-acre (248 ha) estate in Oxney, England, contained BOD_5's up to 100 mg/ℓ and suspended solids up to 2045 mg/ℓ.[4] This study also revealed that the BOD_5 tended to increase with the length of the antecedent dry weather period. The pollution potential of the first flushes of runoff was found to be not much greater than subsequent flow unless there had been a long antecedent dry period. On comparison with a hypothetical combined sewer system for the same area, it was concluded that the separate system reduced the BOD_5 entering the receiving stream but increased the suspended solids load six- or sevenfold.

In 1959 and 1960, in order to determine the effect stormwater runoff was having on the aquatic vegetation of Green Lake in Seattle, Washington, runoff samples were taken from surrounding street gutters.[5] After analyses, the runoff was shown to contain BOD_5's of about 10 mg/ℓ, coliforms up to 16,000 MPN/100 mℓ, nitrate nitrogen to 2.80 mg/ℓ, and soluble phosphorous to 0.78 mg/ℓ. The study recommended discontinuing most urban drainage to the lake.

In 1961, surface runoff from residential and recreational areas in Pretoria, South Africa,[6] was sampled revealing the following results: 30 mg/ℓ BOD_5, 29 mg/ℓ COD, 228 mg/ℓ dissolved solids, 5.4 mg/ℓ total organic nitrogen, and coliform counts of 240,000/100 mℓ. Analyses of runoff samples from nearby commercial areas revealed slightly lower figures for all of the above parameters except BOD_5, which was found to be slightly greater.

A more comprehensive study on the quality of stormwater runoff was conducted by Weibel et al. between 1962 and 1964.[7] Water samples taken from a separate storm sewer system draining 27 acres (11 ha) of residential and light-commercial urban land in Cincinnati, Ohio, revealed the following constituent averages: 227 mg/ℓ suspended solids, 57 mg/ℓ volatile suspended solids, 111 mg/ℓ COD, 17 mg/ℓ BOD_5, 1.0 mg/ℓ inorganic nitrogen, 1.1 mg/ℓ total hydrolyzable phosphate, and 1.7 mg/ℓ organic chlorine. The average coliform density in 90 percent of the samples was 2900/100 mℓ, but individual samples varied widely.

The BOD_5 and COD figures were, on the average, comparable to typical secondary sewage treatment effluent, while suspended solids concentrations were generally comparable to raw sewage. The above-mentioned nutrient concentrations exceeded the 0.3 mg/ℓ inorganic nitrogen and 0.03 mg/ℓ inorganic phosphate indicated as threshold levels for algal blooms. The coliform density considerably exceeded the criterion of 1000/100 mℓ commonly used as a maximum for swimming waters in the United States. A further comparison of surface runoff to domestic sewage is shown on the following page.

Constituents	Raw Domestic sewage (lb/day/acre)	Raw Domestic sewage (lb/yr/acre)	Urban runoff loads as percentage of sewage loads During runoff	Urban runoff loads as percentage of sewage loads Annually
Suspended solids	1.5	540	2400	160
COD	2.6	960	520	33
BOD_5	1.5	540	110	7
Total PO_4	0.19	68	70	5
Total N	0.23	82	200	14

A stormwater sampling program was performed by Bryan[8] in Durham, North Carolina, between May 1969 and February 1970, to determine the quality of storm runoff and the effect of land use on the quality. The 1067-acre (433 ha) drainage basin studied comprised a mixture of land uses typical of urban areas in North Carolina. The population density averaged about 9 persons per acre (22.5/ha).

The water quality characteristics of the sampled runoff were in general agreement with the findings of other studies. The total solids contribution of the urban runoff was substantially larger than the expected average raw sewage wastewater from the same basin. The BOD_5 of the runoff was estimated to equal sanitary effluent from a secondary treatment plant, while COD was greater than raw sanitary effluent from a strictly residential, average, urban area. The contribution of phosphates was nominal in comparison with domestic wastewater.

Obvious relationships between land use, population density, and other numerical characteristics of the subbasins and the measured pollution parameters could not be established because of the amount and type of data generated.

A detailed and comprehensive study by AVCO Corporation[9] was conducted during the fall of 1968 to determine the magnitude of stormwater pollution from urban land areas in Tulsa, Oklahoma. Stormwater samples from selected test areas were collected and analyzed for the usual pollution parameters. As a result of these tests, statistical analytical procedures were developed to relate runoff pollution to land-use variables.

The major sources of pollutants were considered to be material deposited on impervious surfaces (street litter) and material eroded or picked up from drainage channels. The largest amounts of pollutants were generated during the season of greatest runoff.

The land surface characteristics which showed the highest correlation with stormwater pollutant concentrations were (1) environmental conditions, (2) geomorphic characteristics that affect drainage, and (3) the degree of land development. A good prediction variable for bacterial pollution parameters was found to be the general sanitary conditions of the site. BOD_5 concentrations decreased with increasing runoff flow, but the total amount of BOD_5 increased with the increasing flow.

In residential areas, the runoff pollution per unit area increased with population density and/or the number of developed parcels. In commercial and industrial areas, runoff pollution per unit area actually decreased with the number of persons visiting the area. This was explained by suggesting that, as the number of daily visitors increased, the degree and frequency of maintenance operations increased.

2. Characteristics of Street Surface Contaminants

A study by the American Public Works Association[10] was conducted in Chicago during the summer of 1967 to determine the factors in the urban environment which contribute to the pollution of stormwater runoff. Although several sources of runoff pollution were recognized in the study, including street litter, catch basins, roof discharges, and various chemicals, only street litter was extensively sampled and analyzed for its water pollution potential.

A significant aspect of the study was the calculation of street litter accumulation rates for various land uses. This rate was found to range from 0.5 to 8 lb/day/100 ft of curb. Average loadings varied from 2.4 lb/day/100 ft of curb in single-family residential areas to 4.7 lb/day/100 ft of curb in commercial areas.

Although the amount and composition of street litter was found to vary with the day of the week, the season, land use, population density, and pedestrian and vehicular traffic, the main component, by weight, was nearly always the dust and dirt fraction (less than 1/8 in. in size). The total dust and dirt fraction varied from 45 to 83 percent of the total litter. The accumulation rate varied from 0.4 to 5.2 lb/day/100 ft of curb. The accumulation rate by land use was as follows: single-family residential, 0.7 lb/day/100 ft of curb; multiple-family residential, 2.3 lb/day/100 ft of curb; and commercial areas, 3.3 lb/day/100 ft of curb.

The water pollution potential of the street litter was based on an analysis of the soluble portion of the dust and dirt fraction. Approximately 3 percent of the total dust and dirt was soluble. The weighted average amounts of the constituent pollution parameters were as follows: 5 mg/g BOD_5, 40 mg/g COD, 0.48 mg/g total nitrogen, less than 0.05 mg/g phosphates, more than 10 million/g total bacteria counts, more than 1 million/g coliforms, and 5400 mg/g fecal enterococci.

The most determinable measure of pollution potential was deemed to be the BOD_5 of the dust and dirt. Thus, based on a BOD_5 of 5 mg/g or 0.8 lb/day/street mile, the average pollution potential of street litter was estimated at 1 percent of raw sewage and 5 percent of secondary treatment effluent BOD_5.

The maximum peak pollution flush of stormwater runoff was also calculated and compared to raw and treated sewage. It was assumed that the shock loading effect of runoff would occur when all soluble contaminants in a two-week accumulation are washed off the street within a single two-hour runoff period. The BOD_5 of the runoff generated under these conditions was calculated at 11.2 lb/mile of street. This level is approximately equivalent to 160 percent of raw sewage BOD_5 and 800 percent of secondary treatment effluent during the two-hour runoff period.

Catch basins were also determined to be a significant source of shock pollution. The solids that accumulate in catch basins take on the characteristics of anaerobic sludge and the standing water becomes septic. This water and some of the solids can be released into the storm sewer during even minor rainfall or thaw. Water sample taken from a catch basin in a residential area revealed a BOD_5 of 60 ppm.

An extensive study on the water pollution aspects of street surface contaminants was recently conducted by URS Research Company for the Environmental Protection Agency.[11] In this study, samples of street litter were collected from eight representative cities across the United States. Sample collection methods included the use of a rain simulator to ensure the collection of very fine, soluble materials that are often not picked up by dry sweeping techniques. The samples were analyzed for the following pollutants: BOD_5, COD, total and volatile solids, Kjeldahl nitrogen, nitrates, phosphates, and a range of pesticides and heavy metals.

The results of this study were even more alarming with respect to the water pollution potential of street runoff than the previous mentioned studies.

Calculations based on a hypothetical but typical U.S. city* indicated that the pollution load of street surface runoff during the first hour of a moderate-to-heavy storm (brief peaks to at least 0.5 in./hr) would be many orders of magnitude greater than the same city's untreated sanitary sewage during the same time period. A comparison of the pollution load of runoff with raw sewage and secondary treatment effluent is shown as follows:

CALCULATED QUANTITIES OF POLLUTANTS WHICH
WOULD ENTER RECEIVING WATERS IN A HYPOTHETICAL CITY

	Street surface runoff (following 1-hr storm) (lb/hr)	Raw sanitary sewage (lb/hr)	Secondary plant effluent (lb/hr)
Settleable plus suspended solids	560,000	1,300	130
BOD_5	5,600	1,100	110
COD	13,000	1,200	120
Kjeldahl nitrogen	880	210	20
Phosphates	440	50	2.5
Total coliform bacteria (org/hr)	$4,000 \times 10^{10}$	$460,000 \times 10^{10}$	4.6×10^{10}

Note: Since the above calculations were based only on a 5-day accumulation of street litter, the above discharge of contaminated runoff could conceivably occur many times in a year.

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*The hypothetical city has the following characteristics:

- Population - 100,000
- Total land area - 14,000 acres
- Land-use distribution:
  - residential - 75%
  - commercial - 5%
  - industrial - 20%
- Streets (tributary to receiving waters) - 400 curb miles
- Sanitary sewage - 12 mgd

The loading intensities (lb/curb mile) of street surface contaminants, expressed as weighted average values for all samples, were found to be as follows: total solids, 1400 lb/curb mile; volatile solids, 100 lb/curb mile; BOD_5, 13.5 lb/curb mile; COD, 95 lb/curb mile; phosphates, 1.1 lb/curb mile; nitrates, 0.094 lb/curb mile; Kjeldahl nitrogen, 2.2 lb/curb mile; total coliforms, 99×10^9/curb mile; and fecal coliforms, 5.6×10^9/curb mile. Substantial quantities of organic pesticides were found in most samples. The total amount for the cities tested was 0.001 lb/curb mile. However, the amounts varied considerably from site to site. Both chlorinated hydrocarbons and polychlorinated biphenyl compounds (PCB) were found rather consistently. Significant amounts of heavy metals were also detected. Zinc and lead were the most prevalent, measuring 0.65 and 0.20 lb/curb mile respectively.

Because of the consistent presence of heavy metals in amounts large enough to interfere with BOD_5 measurements, COD tests were considered to provide a better basis for estimating the oxygen demand potential of street surface contaminants.

A sizable percentage of the pollution potential of street debris was found to be contained in the very fine silt-like fraction ($< 43\ \mu$). Although this material accounted for only 5.9 percent, by weight, of the total solids in street surface, it contained approximately one-fourth of the total oxygen demand and perhaps one-third to one-half of the algal nutrients. This material also accounted for more than half of the heavy metals and nearly three-fourths of the total pesticides. These concentrations of pollutants in the very fine material are of particular importance because conventional street sweeping operations are rather ineffective in removing this material.

The quantity or loading intensity of material at a given test site was found to be dependent on a number of factors, including surrounding land use, elapsed time since the last sweeping or rainfall, volume and character of local traffic, condition and type of street surface, season of the year, and public works practices. The overall weighted average loading intensity for all samples was computed to be approximately 1400 lb/curb mile. In general, industrial areas contained substantially heavier than average loadings, while commercial areas were considerably below the average. Industrial areas averaged 2800 lb/curb mile; commercial areas averaged 290 lb/curb mile. Average loading intensities for residential areas were 1200 lb/curb mile, but loadings varied widely from site to site. There was a general tendency for newer, more affluent neighborhoods to be cleaner. Asphalt streets were found to have loadings 80 percent heavier than concrete streets. Streets considered in poor to fair condition had loadings about 2-1/2 times greater than streets in good to excellent condition.

A pattern in loading intensities across a typical street was also revealed. Typically, 78 percent of the material was found within 6 inches of the curb and over 95 percent occurred within the first 40 inches.

It was also determined that the rate at which rainfall washes loose particulate matter from street surfaces depends on three primary factors: rainfall intensity, street surface characteristics, and particle size.

As a result of the findings in the above EPA study, an additional EPA study[12] was performed by URS Research Company to further define the character and distribution of heavy metals contained in city street debris.

This project defined the breakdown of the particulates' compositions by having mass spectrographic analyses performed on various samples. Using these results, the heavy metals which were determined to have the greatest water pollution potential (As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Sr, Ti, Zn and Zr) were analyzed in each of about 75 samples collected nationwide in 10 cities in the previous study.

Other analyses conducted included: size affinities of the metals, solubilities and toxicities of the road surface runoff mixture, and certain organic analyses on selected samples. Additional sampling was conducted on rural road, highway, and airport surfaces; and particulates were analyzed for the following common water pollution parameters: BOD_5, COD and nutrients, plus selected heavy metals, for comparison with values representative of normal city streets.

The loading (lb/curb mile, kg/km) and strength (mg/kg) of the above heavy metals were determined for various land-use categories. The three general land-use categories used for comparison were residential, commercial, and industrial; however, further breakdowns of each of these categories were also defined and compared.

Industrial areas were shown to contain the greatest loadings of heavy metals, while both industrial and commercial areas had the greatest strengths, depending on the particular metal. Cities with high particulate levels of air pollution recorded high loadings of heavy metals.

The concentration of heavy metals in storm runoff was found to be 10 to 100 times greater than in sanitary sewage. On a slug load basis (lb/hr, kg/hr), the metal content of runoff was found to be 100 to 1000 times greater than sanitary sewage. However, the metal content of storm runoff is usually not sufficient to cause noticeable reductions in biological treatment efficiency in plants handling combined sewage/storm drain systems.

The solubilities of heavy metals in a simulated receiving water environment were shown to be low, most being less than 10 percent of the available metal. However, copper, cadmium, lead and zinc were found sufficiently soluble to cause toxic effects to certain aquatic organisms under selected conditions. In most samples, more than half of all the heavy metals occurred as particles smaller than 495 μ. The larger particles ($> 246\ \mu$) were found to be the most soluble.

An analysis of street surface contaminants found on rural roads and highways indicated that the city street particulates have a greater pollution potential on a strength (mg/kg) basis. The BOD_5 strength of city samples was found to be an order of magnitude greater than the rural samples. The heavy metal contents of airport surfaces were found to be quite similar to road surface particulates.

Grease and oil were found to be the major organic constituents of the street particulates, but no definite correlation was established between organic strengths (mg/kg) and land use.

Highway deicing compounds were discussed as a source of urban runoff pollution in an EPA report prepared by Edison Water Quality Laboratory in 1971.[13] High concentrations of highway deicing salts were shown to be common in urban runoff waters during periods of snow melt. Concentrations of chlorides as high as 25,000 mg/ℓ have been found in street surface drainage, and up to 2720 mg/ℓ in storm sewers. Surface streams in urban areas also have been found to contain up to 2730 mg/ℓ chlorides. The adverse impacts that deicing salts have on small lakes and streams have been documented, but their influence on major U.S. rivers appears, at this time, to be relatively minor. Nevertheless, it is recognized that there are inadequate surveillance data available to clearly define this area, and more information is necessary.

Deicing compounds often contain special additives with severe latent toxic properties. Complex cyanides and chromate compounds used as additives have been found in storm sewers. However, little is known of their fate and disposition or of their effects on the environment.

3. Impact of Urban Runoff on Receiving Waters

In a recently completed EPA study,[12] copper, cadmium, lead and zinc contained in street surface runoff were found to be sufficiently soluble to cause toxic effects to certain aquatic organisms under selected conditions (such as soft water).

Bioassay tests conducted in aerated, moderately hard water indicated no toxic effects on stickleback during a 96-hour period. It was determined that the immediate toxic effects of road surface runoff are most likely due to extreme oxygen demand rather than to effects from heavy metals. The most dramatic toxic effects of metals will most likely occur when runoff is discharged into quiescent water where it is allowed to accumulate to toxic concentrations.

About two-thirds of the five-day BOD values was exerted during the first day of discharge of road surface particulates into a simulated receiving water environment. Thus, very high BOD_5 values can cause serious oxygen depletion problems in the receiving water immediately following discharge.

The effect of discharge from a separate storm sewer system in Ann Arbor, Michigan, was measured following a storm in 1964.[14] The DO level in the Huron River was depressed from about 10 mg/ℓ to 2 mg/ℓ. The depressed DO level lasted about 24 hours after the end of the storm and affected the river 2 miles below the storm sewer outfall.

4. Control Measures

A thorough discussion of control measures needed to reduce the pollution potential of urban runoff is contained in the American Public Works Association report.[10] The following list is an outline of their major recommendations for effective control and reduction of runoff pollution.

1. Public cooperation -- in reducing the amounts of street litter
2. Street sweeping improvements -- for reducing accumulations of urban street litter
3. Catch basin design and operation improvements -- for reducing discharges of supernatant liquids and entrained sludge
4. Roof drainage controls -- to reduce overloading of combined sewers
5. Improved regulation and enforcement procedures -- for reducing urban littering

6. Land drainage modifications -- for reducing or eliminating the runoff of polluted waste waters and to minimize the import of waters containing snow and ice control chemicals
7. Reduction in indiscriminate use of chemicals -- for control of unwanted pest infestations and the improvement of soil and plant nutrient conditions, and
8. Management-labor relations practices -- to minimize waste collection and other municipal sanitation work stoppages.

In the AVCO Corporation study,[9] land-use practices such as improved urban planning and land-use regulations were stressed as important control measures for urban runoff pollution.

As a result of tests performed on the effectiveness of public works practices during the EPA-sponsored study on street surface contaminants,[11] the following selected recommendations were made to improve the control of urban runoff pollution: better training of cleaning equipment operators, proper maintenance of cleaning equipment, improved street maintenance, auto parking controls, and improved curb design. It was also recommended that public works departments seriously consider eliminating catch basins from particular systems.

During this study, it was revealed that the efficiency of street sweeping programs in the removal of the dust and dirt fraction of street debris is low. The overall removal effectiveness of dust and dirt was determined to be only 50 percent. The removal efficiency of conventional street sweepers was found to be dependent on particle size. Sweeper efficiency ranged from 79 percent for particles 2000 microns in size to only 15 percent for particles less than 43 microns. The removal effectiveness for larger litter (i.e., paper, wood, leaves, etc.) ranged from 95 to 100 percent.

Increased removal effectiveness of present state-of-the-art street sweepers was shown to be possible by decreasing the operating speed or conducting multiple passes. However, to increase the overall effectiveness from the normal (50 percent) to 70 percent would require twice the normal effort.

A comprehensive report evaluating the various approaches to control and treatment of stormwater runoff is currently being prepared by Metcalf and Eddy under an EPA contract.

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Appendix A

DATA ACQUISITION AND PROCESSING FOR CONTAMINANT LOADING RATES AND MATERIAL COMPOSITION

Appendix A

DATA ACQUISITION AND PROCESSING FOR CONTAMINANT LOADING RATES AND MATERIAL COMPOSITION

1. Literature Sources

The objective of this stage of the manual is to determine the rates at which solids accumulate on street surfaces and the chemical and biological composition of those solids as they relate to land use, climate, average daily traffic, and other common parameters. The method for achieving this objective was not to design new experiments but to extract the necessary data from available published literature. Accordingly, the URS staff conducted a search and analysis of this literature to obtain data which would fit into an idealized data matrix or *a priori* model.

Conceptually, rates of solids accumulation (loading rates) and the composition of the accumulated solids should vary from place to place as a function of certain independent variables such as land use, average daily traffic, climate, season, population density, the fraction of the land covered by solid surfaces, the median income of the population in the watershed, and the type of landscaping in the watershed. It is conceivable that, given enough data, an equation could be written relating the loading rate and chemical composition to each of these independent parameters.

It became apparent quite early in the analysis of the available literature that in no single publication were all of the desired independent parameters presented along with the loading rate and composition. Of the several parameters which could have been included in an idealized data matrix, relatively few were sought on a regular basis. These parameters are listed in Table A-1 as independent and dependent parameters. Some of the independent parameters are represented by numerical codes.

Table A-1. DATA ACQUIRED FOR THE ANALYSIS

	Item	Parameter	Abbreviation
Independent Parameters	1	City	
	2	Climate[a]	C
	3	Season[a]	S
	4	Land use[a]	LU
	5	Population density	PD
	6	Average age of the structures in the area, in years	AA
	7	Fraction of the area covered by impervious material	IF
	8	Average daily traffic (number/day)	ADT
	9	Type of street surface[a]	S
	10	Condition of the street[a]	C
	11	Type of landscaping in the area beyond the sidewalk[a]	A
	12	Fraction of the area as road surface	FRS
	13	Days since last rain	R
	14	Days since last swept	S
	15	Method of cleaning[a]	M
Dependent Parameters	16	Loading rate in pounds per curb mile per day	LOAD
	17-32	Organic and inorganic constituents in μg/g of dry solids. Self-explanatory as follows: BOD$_5$, COD, Ortho PO$_4$, total PO$_4$, NO$_3$, NH$_4$, organic N, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Sr, and Zn.	
	33-34	Coliforms, total coliforms and fecal coliforms in numbers per gram of dry solids based on the most probable number methods (MPN).	
	35-42	Pesticides and toxic organics: endrin, dieldrin, PCB, methoxychlor, DDT, lindane, methyl parathion, and DDD in μg/kg of dry solids.	

[a] For numerical codes see Table C-2.

listed in Table A-2. The original intention in assigning these codes was to represent the real variable (conceptually only) by a substitute (surrogate) variable which is proportional to the real variable. Unfortunately, these particular independent parameters cannot be assigned surrogate variables that meet this criteria. For example, the increasing numerical codes for climate and season do not necessarily go in any direction relative to the loading rate or composition, Thus, these codes cannot be thought of either as true continuous variables or as surrogate variables. The distinctions between categories as represented by the codes are often gross; the climatic distinction as shown in Figure A-1 and Table A-3 is particularly so, but the number of available data records would permit no further refinement. It is important to distinguish between areas which receive substantial amounts of snow from those which receive none, and between areas where rain occurs frequently and uniformly throughout the year from those where rains are seasonal. Basically, this is all that the climatic coding performs.

Approximately 150 publications were initially selected for review. Of these, about half were deleted from the list because they were too general in their approach to pollution from stormwater runoff. The remaining 70 publications were carefully analyzed and, finally, only 13 provided enough data to be included in the initial data matrix. These sources provided 153 valid data records. None of the records provided all of the parameters listed in Table A-1. The available data ranged in quality and usefulness from a low, wherein the workers merely declared that there were indeed materials on the streets which contained a high pollutional potential, to a high, wherein the workers accurately catalogued their test areas and carefully described their methods of sample collection and analysis. Several publications that contained data in a form otherwise consistent with that desired were rejected from consideration because the collection and analysis methods either were described incompletely or did not appear to be consistent with those used in the bulk of the available data records.

Table A-2. CODES FOR INDEPENDENT VARIABLES

Item	Parameter	Subcategory	Numerical Code
2	Climate (see Figure A-1 and Table A-3)	Northeastern	1
		Southeastern	2
		Midwestern	3
		Southwestern	4
		Northwestern	5
3	Season	Annual	0
		Winter	1
		Spring	2
		Summer	3
		Autumn	4
4	Land use	Open land	10
		General residential	20
		Low income/old/single	21
		Low income/old/multi	22
		Median income/new/single	23
		Median income/old/single	24
		Median income/old/multi	25
		General commercial	30
		Central Business	31
		Shopping center	32
		Light industry	40
		Medium industry	51
		Heavy industry	52
9	Types of street surface	Asphalt	1
		Concrete	2
10	Condition of the street	Excellent	0
		Good	1
		Fair	2
		Poor	3
11	Area beyond sidewalk	Lawns or grass	1
		Trees	2
		Landscaped buildings	3
		Pavement or bare	4
15	Method of cleaning	Swept and flushed	1
		Swept only	2
		No cleaning	3

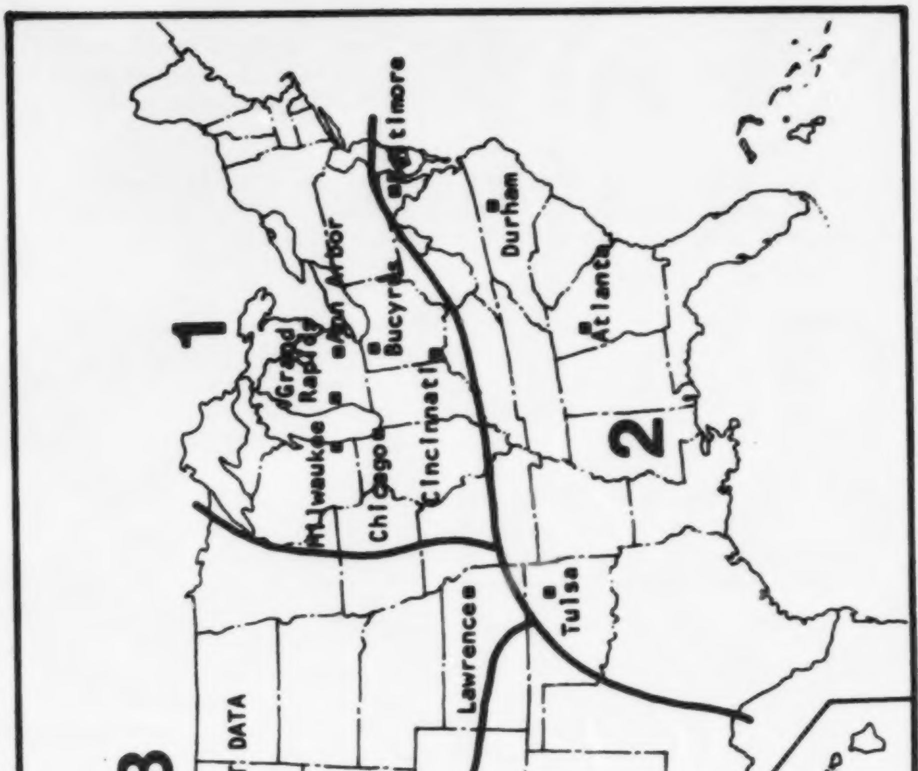
5
Seattle
San Jose
3
INSUFFICIENT DATA
4
Phoenix
Tucson
Lawrence
Tulsa
Milwaukee
Chicago
Cincinnati
Grand Rapids
Ann Arbor
Bucyrus
1
Baltimore
Durham
Atlanta
2

Figure A-1. Climate Zone Codes for the Data Matrix and Cities for Which Data Are Available

Table A-3. CLIMATOLOGICAL CATEGORIES

Code	Description
1	Precipitation is not seasonal but relatively even year round. Winters are cold with snow; summers are moderate to hot and humid. Extremes in climate summer to winter. Precipitation is about 40 inches/year.
2	Precipitation is about 40 inches/year divided about evenly throughout the year. Summers are hot and humid; winters are mild and wet with little snow.
3	Precipitation is less than 30 inches/year but about evenly divided. Summers are hot; winters are arctic and long. Suffers from great plains or tundra type weather with wind and violent storms.
4	Precipitation is light and seasonal with about 10-20 inches/year, falling mostly in winter. Summers are hot and dry; winters are moderate with rain. Snow only in higher elevations.
5	Precipitation is about 40-60 inches/year and seasonal, falling mostly in winter. Winters are cold but not arctic. Frequent snowfalls but precipitation largely as rain. Summers are moderate and dry.
6	National average climate. This is a meaningless category and was employed only to give the computer a code to reject average climate values into.

Generally, analyses for nutrients and trace metals involved some form of preliminary chemical extraction of either the dry street dirt or of the whole runoff sample. The terminal analyses on the extract were performed by accepted colorimetric or atomic absorption methods. The BOD_5, COD, and pesticides analyses were performed either directly on solids or on suspensions of the solids according to Standard Methods. Methods of bacteriological analyses varied slightly between workers, but the precision of the bacteriological analysis is notoriously poor. The solids consist of the suspended load in those samples collected at outfalls and of fine solids which pass a 1/8-inch screen in those samples of dry dust collected directly from the street.

Four individual studies carried out for EPA provided the bulk of the data. They are the Tulsa Study (Storm Water Pollution From Urban Land Activity, AVCO Economic Systems Corp, 11034 FKL, 7/70); the Chicago Study (Water Pollution Aspects of Urban Runoff, APWA for FWPCA, 1/69); the URS I Study (Water Pollution Aspects of Street Surface Contaminants, URS Research Company for EPA, 11034 FUJ, 11/72); and the URS II Study (Toxic Materials Analysis of Street Surface Contaminants, URS Research Company for EPA, 1/73). In the Tulsa Study samples were collected at the main outfall from 16 watersheds within the city. The samples presumably contained only fine suspended solids and no large pieces. In the Chicago Study, samples were collected by sweeping and vacuuming only. This method is known to leave behind small particles in surface interstices which can float out when wet. In both studies by URS Research, street dirt samples were collected by both sweeping and flushing.

Since no standardized techniques for collection and analysis of street surface contaminants have been established, the variance in the data collected from the open literature is expected to contain a large component due to variations in methods. This variance component can be neither eliminated nor evaluated at this time.

2. Data Transformation and Augmentation

There were 14 independent and 27 dependent parameters recorded in the data matrix. These parameters are described in Table A-1. The dependent parameters were expressed by a variety of units in the literature examined. These were transformed into units of parts per million (ppm) of total solids for inclusion in the matrix. Therefore, the concentrations are directly related to loading rates, that is, ppm of solids on the street as expressed in any units desired (e.g., micropounds per pound or micrograms per gram of dry solid). Loading rates were recorded in the literature by several units also. These were transformed to pounds per curb mile per day. For most of the data, this transformation involved no guesswork or indefensible assumptions. However, whenever loading rates were recorded in the literature as pounds per acre of watershed per time unit, it was necessary to assume that only street runoff contributed to this solids load because there was no way to estimate the contribution from soil erosion. This latter contribution is expected to be small except where active construction work is in progress. Daily loadings on a per curb mile basis were obtained by dividing the loading per acre by the curb miles per acre in the watershed. The latter figure, fortunately, was usually available in the publication. This type of transformation was necessary for data from the Tulsa Study and a few other smaller studies.

Very few of the literature sources provided an adequate cataloging of the independent parameters. Population density, fraction of the area covered by impervious material, average age of the structures in the area, and the fraction of the area as road surface were not available from enough sources to make them generally useful parameters. Data on the condition of the street, the street surface material, cleaning method, and days since the street was last swept or rain had fallen were generally available only from the URS Research studies. These parameters were used for separate analyses described later. Those parameters that were consistently available in the literature sources were land use, climate, season, and type of landscaping in the area beyond the sidewalk. Average daily traffic (ADT) was determined from traffice maps obtained from the traffic engineer's office of the city of interest. Occasionally, if these parameters were not explicitly stated in the publication, they were obtained from a picture of the area or from a verbal description given over the telephone by the city engineer.

In those areas where the study was conducted on a whole watershed, the ADT was calculated by a circuitous method described as follows. A unit area was selected for the given city. It was then assumed that people enter and leave the area ultimately by major arteries and that one arrival or one departure constituted one ADT unit. The total traffic into and out of the area was determined and expressed as ADT per acre of area. Finally, ADT was expressed as number per day per curb mile of road by dividing the ADT per acre by the highway density in curb miles per acre. This unit is different from the regular ADT; but the unit length, the curb mile, is a standard unit used in the daily loading values and was believed to be acceptable for categorizing a given watershed area as lightly or heavily traveled. These values are recorded without distinguishing marks in the data matrix.

To facilitate the operation of reading the data into the computer, the total coliform (TCOLI) and fecal coliform (FCOLI) numbers were represented with the exponential notation, e.g., 2.0 E6 is equivalent to 2.0×10^6.

Chlorinated hydrocarbon and mercury analyses were available only in the URS I study. Since they were so few in number, these data were separated out of the data matrix and treated individually. All of the data available except the chlorinated hydrocarbon and mercury analyses are shown in Table A-4. The chlorinated hydrocarbon and mercury concentration data are given in Table A-5 along with the basic statistics of these data sets.

CITY	C	S	LU	FD	AA	IF	ADT	B	C	A	PRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
DURHAM	2	0	20	9.7	10	.29	2900	1	1	1	.20				430	5300	65500		212								117						1.1E5
DURHAM	2	0	20	10.5	10	.34	4200	1	1	1	.24				620												137						
DURHAM	2	0	20	8.2	10	.20	2000	1	1	1	.13				390												46						
LAWRENCE	3	0	20			.38	2500	1	1	1					210	12900	61600			11600													
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						167000	611000	6670		2720	5390	6670										2.8E6	5.9E5
CINCINNATI	1	4	30	9	20	.37	5600	2	1	1						175000	525000	5050		1810	4940	11980											
CINCINNATI	1	1	30	9	20	.37	5600	2	1	1						46200	423000	1810		1920	1880	6920											
CINCINNATI	1	2	30	9	20	.37	5600	2	1	1						76000	400000	2640		1960	3280	9000											
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						78900	526000	5790		3110	2630	10500											
ANN ARBOR	1	2	20				5600			4						18500		650	2620	650	595	535											
ANN ARBOR	1	3	20				5600			4						30700		950	2770	800	730	365											
ANN ARBOR	1	4	20				5600			4						21300		220	2130	440													
GRAND RAPIDS	1	0	40				5600			4													0.7	9	14	3100	47		8		57		
GRAND RAPIDS	1	0	20				5600			4													0.4	3	8	2200	17		4		21		
GRAND RAPIDS	1	0	10				5600			4													0.6	5	9	2600	15		6		22		
CINCINNATI	1	0	30	9	20	.37	5600	2		1						75000	489000		4850	4400		9250										1.6E6	2.6E5
CINCINNATI	1	0	10	9	20	.37	300	2		1						22300	252000		5440	16000		12800										2.5E5	8.0E3
TUSCON	4	3	20				10000			2							200000	520		2730												8.6E7	1.7E7
TUSCON	4	1	20				10000			2							312000	450		940												2.4E7	7.5E5
TUSCON	4	3	30				14000			1							101000	170		1020												3.4E7	8.2E6
TUSCON	4	1	30				14000			1							147000	230		350												1.5E7	3.5E5
TUSCON	4	3	40				12000			4							201000	240		430												1.0E7	1.0E6
TUSCON	4	1	40				12000			4							274000	760		790												3.3E7	4.6E5
CINCINNATI	1	0	30	7	20	.37	5600	2	1	1					32	109000	497000	4390		2300	3620	8800											
ANN ARBOR	1	0	20				5600			4					170	23500		610	2510	630	660	450											
CHICAGO	1	3	30		20		7950		1	4			1	2	134	5050	26700	38		480												3.5E6	9.7E5
CHICAGO	1	3	30		20		20400		1	4			1	2	326	4030	24800	27		323												5.8E5	3.2E4
CHICAGO	1	3	30		20		13500		2	4			1	2	71	14540	66700	142		457												1.0E6	4.0E3
CHICAGO	1	3	50		20		11140		2	4			1	2	284	2950	23000	30		431												3.2E5	2.7E4
CHICAGO	1	3	20		10		800		1	1			1	2	19	1720	18300	20		325												1.1E6	1.3E5
CHICAGO	1	3	20		15		1000		2	2			3	2	32	9100	53100	70		523												1.1E6	4.1E4
CHICAGO	1	3	20		50		700		2	4			3	2	171	2180	50700	142		523												1.3E6	7.0E5
CHICAGO	1	3	20		50		1980		3	3			3	2	148	2810	29500	21		773												1.2E6	5.7E5
CHICAGO	1	3	20		20		5860		2	2			3	2	81	4770	61300	63		377												2.6E6	6.1E5
CHICAGO	1	3	20		20		5860		2	2			3	2	62	2900	32600	30		405												1.6E6	1.9E5
CHICAGO	1	3	20		15		1828		2	3			3	2	121	2030	34000	24		845												3.1E6	2.7E5
CHICAGO	1	3	20		20		240		2	3			3	2	135	6320	45600	73		670												5.6E6	4.5E5
CHICAGO	1	3	20		50		14070		1	3			3	2	148	2280	24600	20		961												4.1E6	4.0E5
CHICAGO	1	3	20		20		3600		1	2			7	2	19	3240	24500	24		525												1.0E6	1.2E6
CHICAGO	1	3	20		10		1200		1	2			7	2	20	9430	72800	109		523												3.0E6	1.3E6
CHICAGO	1	3	20		10		17300		2	2			3	2	96	1940	32100	28		482												3.9E5	1.5E4
CHICAGO	1	3	50		15		9800		3	1					536	2820	31800	14		410												2.6E6	5.3E5
CHICAGO	1	3	20		20		1620		2	3			7	2	153	3220	34600	30		356												2.1E6	1.0E6
TULSA	2	0	30	.5	5	.30	10100	1	1	4	.15				419	5800	49000	1600				490										3.2E5	4.2E3
TULSA	2	0	30	4.0	5	.55	10600	2	1	3	.20				46	29300	163000	3200				3600										1.6E6	6.9E4
TULSA	2	0	20	7.1	5	.27	3800	1	1	1	.19				60	11600	91700	2800				2200										1.5E6	4.8E4
TULSA	2	0	50	3.8	20	.51	10200	1	1	4	.23				88	23200	168000	1800				1600										4.1E5	1.3E4
TULSA	2	0	20	8.9	50	.30	14500	2	2	2	.27				22	67300	510000	3300				2700										5.5E6	5.5E4
TULSA	2	0	50	3.2	20	.24	6600	1	2	4	.23				25	35000	267000	2500				1800										4.0E6	5.2E5
TULSA	2	0	20	11.5	20	.32	8300	2	1	1	.24				32	19000	114000	1600				1900										7.7E5	2.9E3
TULSA	2	0	20	11.3	20	.37	6100	1	1	2	.28				35	39300	298000	3000				1800										6.3E6	1.2E4
TULSA	2	0	20	13.6	20	.31	3800			3	.37				24	24000	277000	2400				1600										9.6E6	7.0E3
TULSA	2	0	30	4.3	20	.74	2600	2	1	2	.51				41	25300	247000	1600				1900										3.0E6	7.0E3
TULSA	2	0	20	9.5	50	.41	3200		3	2	.42				33	25000	207000	1500				1200										6.4E6	1.1E4
TULSA	2	0	40	0.0	10	.46	0	2	1	1	.48				57	39600	222000	2700				1900										2.8E6	5.0E2
TULSA	2	0	20	2.3	10	.23	8000	1	1	1	.20				41	32100	192000	2600				3100										6.0E5	3.8E3
TULSA	2	0	10	.9		.11	0			1	.08				12	18200	90900	1700				1700										8.4E4	6.3E3
TULSA	2	0	20	11.2	20	.38	10200	1	1	2	.22				28	43900	158000	3000				1400										8.1E6	1.3E4
SAN JOSE I	4	4	20				10400	1		1		14		2	70	17000	34000	770		3600		2300	3.5	304	71	24000	2700	460	96	8	360		
PHOENIX I	4	1	20				11400	1		1		12	6	2	92	10000	46000	340		450		2300	7.2	211	129	21000	1500	540	15	14	340		
MILWAUKEE	1	2	20				10100	1		1		0	7	2	2700	4400	18000	100		20		530	2.7	147	160	18000	830	280	22	28	280	4.0E4	5.7E0
BUCYRUS	1	2	20				1200	1		1		2		2	690	2100	21000	180		89		890	2.7	180	90	21000	890	470	17	33	250		
BALTIMORE	2	2	20				10900	1		1		26	4	1	260	61000	20000	1000		38		1900	8.0	273	160	24000	2200	480	31	21	440	1.0E5	
SAN JOSE II	4	2	20				10900	1		1		59		2	860	8900	68000	750		45		1800	4.3	245	78	28000	3400	460	87	16	400	2.6E4	2.0E2
ATLANTA	2	2	20				7200	1		1		2	14	1	220	4500	30000	620		55		1100	1.1	220	120	24000	660	350	19	4	330	1.6E5	1.5E4
TULSA	2	2	20				7200	2		1		9		1		43000	91000	1700		37		2000	1.7	112	91	12000	740	340	9	63	240	1.1E6	2.5E5
PHOENIX II	4	2	20				11400	1		1		60		2		11000	58000	3000		130		3200	0.7	141	67	15000	620	490	11	16	210	1.2E5	5.8E3
SEATTLE	5	3	20				11700	1		1		12		1		10000	38000	1100		59		2000	1.1	243	89	29000	2100	460	32	11	480	7.7E5	9.1E3
LOW/OLD/SING	6	0	[illegible]				5600	1		1					372	10000	32000	1100		64		2200	2.5	208	119	24000	1500	420	38	26	370	2.1E5	2.3E4
LOW/OLD/MULT	6	0	22				8000	1		1					659	22000	26000	1100		64		2200	3.6	188	90	20000	1900	330	28	19	360	1.5E5	1.2E4
MED/NEW/SING	6	0	23				2500	1		1					418	12000	40000	1100		64		2200	3.3	192	81	18000	1200	420	36	32	290	4.2E5	1.4E4
MED/OLD/SING	6	0	24				1400	1		1								1100		64		2200	2.8	183	94	20000	1600	370	13	18	530		
MED/OLD/MULT	6	0	25				10800	1		1						7100	24000	1100		64		2200	3.1	178	79	24000	1900	330	14	12	350	1.1E5	2.1E4
CENT.BUS.	6	0	31				15500	1		4					296	8300	30000	1000		600		1600	6.5	247	88	24000	3600	420	46	20	640	1.1E5	1.1E5
SHOP.CENTER	6	0	32				18800	1		4					122	8600	21000	1000		600		1600	3.7	205	259	23000	3600	370	57	16	400	2.0E6	5.2E5
LIGHT IND.	6	0	40				8300	1		4					946	15000	73000	1400		72		1600	4.4	288	130	22000	2800	490	44	24	400	3.7E5	6.9E5
MED. IND.	6	0	51				9100	1		4					264	11000	60000	1400		72		1600	3.2	244	87	23000	1400	420	35	24	280	2.3E5	1.3E3
HEAVY IND.	6	0	52				9800	1		4						3700	17000	1400		72		1600	4.7	304	159	40000	470	870	33	17	390	1.2E4	4.5E2

Table A-4. ENTIRE MATRIX OF AVAILABLE DATA

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
SAN JOSE I	4	4	21				9400	1	1	1		12		2	70								3.5	325	88	27000	2400	450	85	19	320		
SAN JOSE I	4	4	22				12050	1	2	1		13		2	85								3.5	325	96	23000	2000	450	80	17	370		
SAN JOSE I	4	4	23				300	1	1	1		12		2	24								4.5	295	33	21000	2100	350	100	5	260		
SAN JOSE I	4	4	31				3600	1	2	4		13		2	21								2.6	320	110	16000	3500	470	110	20	600		
SAN JOSE I	4	4	32				13000	1	1	4		18		2	26								8.0	325	80	44000	7600	410	93	10	410		
SAN JOSE I	4	4	40				7250	1	2	4		13		2	131								3.4	300	87	24000	2000	500	110	0	350		
SAN JOSE I	4	4	51				7200	1	1	4		18		2	61								2.2	285	67	26000	3500	600	93	8	450		
PHOENIX I	4	1	21				2700	1	2	1		12	8	2	77								4.0	203	150	23000	1200	320	0	17	290		
PHOENIX I	4	1	22				11100	1	2	1		12	1	2	238								5.5	159	39	17000	3700	280	0	13	210		
PHOENIX I	4	1	23				10300	1	0	1		12	7	2	18								8.8	215	140	21000	970	680	25	13	330		
PHOENIX I	4	1	25				11000	1	2	1		12	3	2	34								6.0	238	53	23000	3600	440	5	12	490		
PHOENIX I	4	1	31				11900	1	2	4		12	1	2	26								6.6	190	69	15000	3200	380	6	15	335		
PHOENIX I	4	1	32				15000	1	1	4		12	13	2	53								2.0	168	25	15000	1600	360	7	11	720		
PHOENIX I	4	1	40				12300	1	1	4		12	10	2	41								11.	208	100	20000	2500	430	6	15	230		
PHOENIX I	4	1	51				17200	1	0	4		12	8	2	130								1.7	256	38	24000	1200	330	1	12	210		
MILWAUKEE	1	2	21				14000	1	1	1		0	7	2	103								4.2	130	83	15000	790	280	33	21	300	9.9E4	2.6E1
MILWAUKEE	1	2	22				4000	1	3	4		0	6	2	93								1.4	141	170	14000	580	230	0	24	210		
MILWAUKEE	1	2	23				300	2	1	1		0	7	2	40								0.6	153	120	18000	970	250	26	76	250		
MILWAUKEE	1	2	25				16000	1	2	1		0	9	2	770								2.3	125	72	15000	470	290	18	20	210	8.0E4	
MILWAUKEE	1	2	31				6000	1	0	4		0	1	2	260								3.9	190	810	25000	2700	300	30	20	650	3.1E4	
MILWAUKEE	1	2	32				20800	2	2	4		0	7	2	30								3.2	177	120	34000	2200	390	37	7	320		
MILWAUKEE	1	2	51				12000	1	2	4		0	8	2	51								6.3	179	120	22000	660	270	21	20	370	2.7E4	
MILWAUKEE	1	2	52				8000	1	2	4		0	8	2	1500								1.6	128	170	15000	360	310	30	9	220		
BUCYRUS	1	2	21				300	1	3	1		2		2	950								3.0	132	91	13000	350	420	13	33	190		
BUCYRUS	1	2	23				300	1	0	1		2		2	205								2.6	138	66	15000	430	370	36	33	110		
BUCYRUS	1	2	24				300	1	0	1		2		2	950								1.6	178	94	22000	1600	490	7	41	390		
BUCYRUS	1	2	51				300	1	0	1		2		2	500								4.7	335	120	43000	780	620	35	24	200		
BUCYRUS	1	2	52				5000	1	3	4		2		2	800								4.0	159	78	20000	260	470	6	17	140		
BALTIMORE	2	2	22				6700	1	1	3		26	1	1	100								8.8	210	120	18000	1700	290	45	24	630		
BALTIMORE	2	2	23				700	2	1	1		26	13	1	67								6.1	290	120	24000	1000	430	55	23	760	1.0E5	
BALTIMORE	2	2	24				700	1	0	1		26	5	1	93								5.5	120	120	15000	730	150	2	5	730		
BALTIMORE	2	2	25				8000	1	0	1		26	4	1	33								5.2	215	190	18000	1500	270	18	6	490		
BALTIMORE	2	2	31				14200	1	0	4		26	1	1	5								25.	356	290	40000	5700	770	51	25	1000		
BALTIMORE	2	2	32				27000	1	0	4		26	4	1	4								3.7	264	210	23000	2100	500	7	33	510		
B[illegible]TIMORE	2	2	40				9900	1	2	4		26	3	1	97								8.2	760	280	31000	9999	830	37	34	780		
[illegible]ORE	2	2	51				11000	1	2	4		26	4	1	57								8.8	290	210	25000	1800	680	12	33	410		3.6E3
[illegible]TIMORE	2	2	52				21000	2	0	1		26	4	1	16								6.8	345	150	53000	310	1600	14	38	300		
SAN JOSE II	4	2	21				9400	1	1	1		59		2	11								6.0	295	130	48000	5700	560	120	28	810	5.3E5	2.5E3
SAN JOSE II	4	2	22				12050	1	2	1		59		2	8								2.0	75	34	11000	600	230	30	21	210	1.9E5	1.5E3
SAN JOSE II	4	2	23				300	1	1	1		59		2	3								5.4	245	53	26000	3900	470	75	9	420	9.1E4	3.6E3
SAN JOSE II	4	2	31				23600	1	2	4		59		2	20								4.9	310	84	30000	5100	500	83	15	510	1.8E4	9.0E2
SAN JOSE II	4	2	32				13000	1	1	4		59		2	3								3.1	430	96	23000	9999	540	140	13	380	6.7E5	6.7E3
SAN JOSE II	4	2	40				7250	1	2	4		59		2	204								3.7	306	71	17000	2700	490	120	13	340	4.0E4	6.7E1
SAN JOSE II	4	2	51				7200	1	1	4		59		2	19								4.0	194	92	22000	1500	450	93	18	280	5.8E4	6.1E2
ATLANTA	2	2	21				300	1	1	1		2	14	1	295								0.	182	150	24000	280	210	9	3	270	2.0E5	6.8E4
ATLANTA	2	2	22				300	2	1	1		2	1	1	31																	1.3E6	1.2E4
ATLANTA	2	2	23				300	1	1	1		2	21	1	165								0.	127	70	13000	480	280	7	4	180	1.8E5	4.6E3
ATLANTA	2	2	31				14100	1	1	4		2	1	1	60								5.3	207	300	20000	3900	280	18	13	1100	2.0E5	2.2E2
ATLANTA	2	2	32				34100	1	0	4		2	14	1	215								0.	100	30	12000	2000	290	12	5	320	1.7E5	7.2E3
ATLANTA	2	2	40				5000	1	2	1		2	30	1	1850								1.5	162	140	16000	740	300	19	6	320	8.3E4	5.7E3
ATLANTA	2	2	52				5000	1		1		2	10	1	150								6.4	585	190	72000	940	1100	84	3	880	1.4E5	5.3E2
ATLANTA	2	2	25				300	1	3	1		2	28	1																			
ATLANTA	2	2	51				5000	1	3	1		2	7	1									0.4	275	38	14000	1400	240	12	14	310		
TULSA	2	2	21				5000	1	3	1		9		1	13								1.0	186	160	20000	1100	430	32	78	350	1.4E6	9.3E2
TULSA	2	2	23				700	2	2	1		9		1	69								1.3	150	71	17000	970	520	1	110	190	6.5E5	5.5E2
TULSA	2	2	25				16800	2	2	1		9		1	17								2.4	24	66	1400	230	100	0	6	220	9.4E6	3.4E5
TULSA	2	2	31				18000	1	2	4		9		1	20								1.6	135	96	11000	1300	250	29	37	420	5.6E5	5.2E5
TULSA	2	2	32				5000	2	2	1		9		1									9.3	63	66	8800	2400	160	10	38	190		
TULSA	2	2	40				700	2	1	1		9		1	122								2.8	139	110	15000	1100	440	24	93	360	1.2E5	3.8E1
TULSA	2	2	51				5000	2	2	1		9		1	31								0.	74	64	8100	65	180	26	77	160	7.3E5	9.1E5
PHOENIX II	4	2	21				2700	1	3	1		60		2	27								1.1	185	98	21000	340	700	11	25	350	2.0E5	1.1E4
PHOENIX II	4	2	22				11130	1		1		60		2	18								0.3	165	74	20000	2000	370	3	23	250	1.9E5	5.4E3
PHOENIX II	4	2	23				10300	1	1	1		60		2	6								0.	111	59	11000	220	450	0	12	130	2.5E4	2.7E4
PHOENIX II	4	2	25				11000	1	2	1		60		2	8								0.8	193	46	25000	2900	420	7	15	290	8.6E4	2.2E3
PHOENIX II	4	2	31				11900	1	2	4		60		2	4																	3.5E4	1.1E4
PHOENIX II	4	2	32				15000	1	1	4		60		2	3								6.4	71	98	5000	0	280	170	25	400	4.2E4	1.4E2
PHOENIX II	4	2	40				12300	1	1	4		60		2	4								2.1	188	120	24000	2100	460	18	15	360	1.3E5	8.8E1
PHOENIX II	4	2	51				17200	1	1	4		60		2	18								0.3	310	32	22000	1700	400	23	10	150	2.3E5	7.2E1
SEATTLE	5	3	21				6700	1	3	1		12		1	39								0.	233	89	27000	1700	430	39	13	460	1.6E5	3.2E3
SEATTLE	5	3	22				6900	1	1	3		12		1	45								3.4	239	100	37000	3000	490	40	8	660	6.4E4	3.6E4
SEATTLE	5	3	24				3200	2	1	1		12		1	22								1.3	250	67	23000	2500	460	29	9	460		
SEATTLE	5	3	25				12300	1	2	3		12		1	12								1.6	254	48	58000	2600	440	39		410	3.1E5	2.4E2
SEATTLE	5	3	31				16000	1	2	4		12		1	16								2.3	266	210	32000	3300	430	39	15	500	1.6E5	5.0E3
SEATTLE	5	3	32				26500	1	2	4		12		1	16								1.5	247	63	42000	4700	440	40	0	390	1.8E5	1.5E3
SEATTLE	5	3	40				10000	2	2	4		12		1	59								1.4	239	110	27000	1100	490	20	16	480	3.1E6	9.1E3

Table A-4 (continued)

Table A-5. MEAN CHLORINATED HYDROCARBON AND MERCURY CONCENTRATIONS IN URBAN STREET DIRT FROM SEVERAL U.S. CITIES (THE URS I STUDY)

	Concentration in Micrograms/kilograms of Dry Solid								
City	Hg	Endrin	Dieldrin	PCB	Methoxy-chlor	DDT	Lindane	Methyl Parathion	DDD
San Jose I	330	2.2	12	1300	0	120	19	22	73
Milwaukee	.	0	3.8	1300	3100	0.4	1.2	0	0.2
Bucyrus	.	0	12	470	1200	43	0	0	61
Baltimore	.	0	3.0	1000	170	30	0	0	100
San Jose II	14	0	4.4	100	0	28	0	0	20
Atlanta	53	0	55	150	0	30	0	0	79
Tulsa	59	0	74	200	0	39	0	0	100
Phoenix II	24	0	26	71	0	14	.	0	37
Seattle	75	0	59	2300	0	380	.	0	270
Mean	83	0.2	28	770	500	76	2.9	2	82
Standard Deviation	111		28	770	1050	118	7.1		78
Range	14-330	0-2.2	3.0-74	71-2300	0-3100	0.4-380	0-19	0-22	2-270
N	6	9	9	9	9	9	7	9	9

3. Data Processing

a. Preliminary Evaluation of Data Obtained by URS Research Company

In an earlier study of trace metal concentrations in street surface materials, the URS Research Company had collected raw data in the form of solid load in pounds per curb mile and corresponding days since last the street had been swept or since a substantial rain had last occurred. The usual method for expressing these two data is as a ratio of pounds per curb mile per day since last cleaned by either sweeping or rain, whichever is less. However, theoretically, there is no justification for this type of transformation. Conceptually, it is probably valid to assume that solids accumulate on streets by some process at a constant rate (C), and are removed from the streets by a different set of processes at a rate proportional to the existing load (L). These concepts may be expressed mathematically by the differential equation

$$\frac{dL}{dt} = C - kL$$

where k is a removal constant. The theoretical load of solids on the street at any time (t), starting with a clean street, is expressed as

$$\int_0^L \frac{dL}{C - kL} = \int_0^t dt$$

$$L = \frac{C}{k} (1 - e^{-kt})$$

From the last equation, it is clear that when t is small, the load increases at a constant rate C; and as t approaches infinity, the load approaches assymptotically to the value C/k. Thus, the ratio of L/t (pounds per curb mile per day) appears nowhere in the theoretical treatment. Since the raw data of L and t were available from the URS study, it was decided to attempt to find out whether the data would approximate the conceptual model.

First, the days since rain had fallen or the street had been swept were transformed into equivalent days of accumulation (EDA) by the formula

EDA = (days since last rain - days since last swept)
X (1 - sweeping efficiency) + days since last swept

The assumption inherent in this formula is that the last rain cleaned the street thoroughly. This is a poor assumption, but no data were available from which to estimate the fraction of material washed off by each rain. Generally, it is assumed that a rain intensity of 0.5 inch/hour gets 90 percent of the solids. The days since last rain figure is the days since a rain of this intensity. Obviously, whenever rain had fallen fewer days previous than the street had been swept, the days since last rain was EDA.

Attempts were made to fit EDA and load data by linear regression, polynomial regression, and a theortical curve. To remove the effects of different land use and climate, the data were separated wherever there were enough data records to allow it. No statistically significant relationships could be found between EDA and load in any land use or climatic category. To include potential effects of ADT on the load, these data were included as log ADT and log (ADT x EDA) in a second attempt to find relationships. Attempts were made to fit load with log ADT and log (ADT x EDA) by linear and polynomial regression and with a theoretical curve. No significant relationships were observed. The best correlation coefficient obtained was 0.29. This was obtained with a linear regression between load and log (ADT x EDA) in residential areas in the east, and suggested that load decreased with increasing log (ADT x EDA).

After this abortive attempt to verify the theoretical relationship with data from the real world, the loading data was transformed as usual into the ratio Load/EDA and expressed as pounds per curb mile per day. The results of this preliminary attempt to extract information from data taken from the real world is indicative of the complexity of real systems.

The variance in the loading rate data exceeds the variance of our representation of any single independent parameter as far as can be determined. Therefore, the probability that any combination of independent parameters can describe or predict the loading rate (i.e., will co-vary with the loading rate) is small. The only recourse to extracting information from the data by covariant analyses is by a factor analysis technique. Unfortunately, there are not enough complete data records to permit this kind of study. Furthermore, most of the independent parameters as conceived in this work are not continuous and cannot be mixed with continuous variables in a covariant analysis.

b. Grouping the Data

Since no continuous surrogate variables could be defined to represent the independent parameters, generally one cannot expect to find continuous relationships between the independent and dependent parameters. Since the chances of discovering useful relationships by multiple regression or curve fitting techniques appeared to be poor, an alternative method was adopted for detecting systematic changes in the dependent with changes in independent parameters. The procedure was to (1) group the data records according to the independent parameters, (2) calculate the mean and other basic statistics of the dependent variables so grouped, and (3) test the differences between these means for statistical significance by the student **t** and test. This procedure for grouping the data records provides the mechanism for both detecting significant variations in the grouped data and presenting the available information which is readily usable by the urban planner.

The data grouping operation was performed by computer. The entire matrix in Table A-4 was broken up into 19 primary categories by Land Use, Climate, ADT, and Type of Landscaping Beyond the Sidewalk. There were enough data to allow a breakdown by season also, but it was thought to be redundant with climate and so was not considered. The computer sorted the matrix into groups to these four parameters, according to the codes shown in

Table A-2. These submatrices are shown in Tables A-6 through A-22. Data from URS Research Company's earlier studies that had collected data on the condition and type of street surface was grouped by hand into two street surface types. These groups are not shown.

Each column of data was first scanned by eye and extreme values were discarded in pairs -- a high and a low. The total number of points discarded did not exceed 10 percent of the number available. A single point was discarded only when it was one to two orders of magnitude different from the bulk of the remaining data in the column. The mean, standard deviation, range, and number of data points were calculated and recorded. Standard deviations for means of less than 5 data were considered unreliable and not recorded. The same calculations were performed on the set of all data. These basic statistics are listed in Table A-23.

These basic statistics are useful for testing whether the analysis of a single sample is significantly different from the mean of the published analyses. But in its present form, Table A-23 is much too complex and cumbersome to enable a planner to use it to predict loading rates and composition or to make decisions about whether a mean value in a particular subset is significantly different from the mean of the set of all data. To simplify the presentation of these data, the standard error of the mean $(\overset{*}{\sigma})$ was calculated as

$$\overset{*}{\sigma} = \frac{\sigma}{\sqrt{\eta}} \text{ if } \eta > 10 \text{ or } \overset{*}{\sigma} = \frac{\sigma}{\sqrt{\eta - 1}} \text{ if } \eta < 10$$

where σ is the standard deviation and η is the number of available data. Then $\overset{*}{\sigma}$ was calculated as a percent of the mean as

$$\% \overset{*}{\sigma} = (\overset{*}{\sigma} / \bar{x}) \times 100$$

where $\bar{x}$ is the mean of the column of data. The $\% \overset{*}{\sigma}$, expressing the percent standard error of the mean, is presented as a letter subscript that

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	PRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
GRAND RAPIDS	1	0	10				5600			4													0.6	5	9	2600	15		6		22		
CINCINNATI	1	0	10	9	20	.37	300	2		1						22300	252000		5440	16000		12800										2.9E5	8.0E3
TULSA	2	0	10	.9		.11	0			1	.08				12	18200	90900	1700				1700										8.4E4	6.9E3

Table A-6. LAND USE 10 - OPEN SPACE

CITY	C	S	LU	PD	AA	IP	ADT	S	C	A	FES	R	S	N	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
DURHAM	2	0	20	9.7	10	.29	2900	1	1	1	.20				400	5300	65900		212								117						1.1E8
DURHAM	2	0	20	10.5	10	.34	4200	1	1	1	.24				600												137						
DURHAM	2	0	20	8.2	10	.20	2000	1	1	1	.13				390												66						
LAWRENCE	3	0	20			.38	2500	1	1	1					210	12900	61600			11600													
ANN ARBOR	1	2	20				5600			4						18500		650	2620	650	595	535											
ANN ARBOR	1	3	20				5600			4						30700		950	2770	800	730	365											
ANN ARBOR	1	4	20				5600			4						21300		220	2130	440													
GRAND RAPIDS	1	0	20				5600			4													0.4	3	8	2200	17		6		21		
TUSCON	4	3	20				10000			2							200000	580		2730												8.6E7	1.7E7
TUSCON	4	1	20				10000			2							312000	450		940												2.4E7	7.9E5
ANN ARBOR	1	0	20				5600			4					170	23800		610	2510	630	660	450											
CHICAGO	1	3	20		10		800		1	1			1	2	19	1720	18300	20		325												1.1E6	1.3E6
CHICAGO	1	3	20		15		1000		2	2			3	2	32	9100	53100	70		523												1.1E6	4.1E6
CHICAGO	1	3	20		50		700		2	4			3	2	121	2180	50700	142		523												1.3E6	7.0E5
CHICAGO	1	3	20		50		1980		3	3			3	2	148	2810	29500	21		773												1.2E6	8.7E5
CHICAGO	1	3	20		20		5860		2	2			3	2	81	4770	61300	63		377												2.6E6	6.1E5
CHICAGO	1	3	20		20		5860		2	2			3	2	62	2900	32600	30		405												1.6E6	1.9E5
CHICAGO	1	3	20		15		1828		2	3			3	2	121	2030	34000	24		845												3.1E6	2.7E5
CHICAGO	1	3	20		20		240		2	3			3	2	135	6320	45600	73		670												5.6E6	4.5E5
CHICAGO	1	3	20		50		14070		1	3			3	2	148	2280	24600	20		961												4.1E6	4.0E5
CHICAGO	1	3	20		20		3600		1	2			7	2	19	3240	24500	24		525												1.0E6	1.2E6
CHICAGO	1	3	20		10		1200		1	2			7	2	20	9430	72800	109		523												3.0E6	1.3E6
CHICAGO	1	3	20		10		17300		2	2			3	2	96	1940	32100	28		482												3.9E5	1.5E4
CHICAGO	1	3	20		20		1620		2	3			7	2	153	3220	34600	30		356												2.1E6	1.0E6
TULSA	2	0	20	7.1	5	.27	3800	1	1	1	.19				60	11600	91700	2800				2200										1.5E6	6.8E4
TULSA	2	0	20	8.9	50	.30	14500	2	2	2	.20				22	67300	510000	3300				2700										5.5E6	5.5E4
TULSA	2	0	20	11.5	20	.32	8300	2	1	1	.24				32	19000	114000	1600				1900										7.7E5	2.9E3
TULSA	2	0	20	11.3	20	.37	6100	1	1	2	.28				35	39300	298000	3000				1800										6.3E6	1.2E4
TULSA	2	0	20	13.6	20	.31	3800			3	.37				24	24000	277000	2400				1600										9.6E6	7.0E3
TULSA	2	0	20	9.5	50	.41	3200		3	2	.42				33	25000	207000	1500				1200										6.6E6	1.1E4
TULSA	2	0	20	2.3	10	.23	8000	1	1	1	.20				41	32100	192000	2600				3100										6.0E5	3.0E3
TULSA	2	0	20	11.2	20	.38	10200	1	1	2	.22				28	43900	158000	3000				1400										8.1E6	1.3E4
SAN JOSE I	4	4	20				10400	1		1		14		2	70	17000	34000	770		3600		2300	3.5	304	71	24000	2700	460	96	8	360		
PHOENIX I	4	1	20				11400	1		1		12	6	2	92	10000	46000	340		450		2300	7.2	211	120	21000	1500	540	15	14	340		
MILWAUKEE	1	2	20				10100	1		1		0	7	2	2700	4400	18000	100		20		530	2.7	147	160	18000	830	280	22	28	280	4.0E4	5.7E0
BUCYRUS	1	2	20				1200	1		1		2		2	690	2100	21000	180		89		890	2.7	180	90	21000	890	470	17	33	250		
BALTIMORE	2	2	20				10900	1		1		26	4	1	260	61000	20000	1000		38		1900	8.0	273	160	24000	2200	480	31	21	640	1.0E8	
SAN JOSE II	4	2	20				10400	1		1		59		2	860	8900	68000	750		45		1800	4.3	245	75	25000	3400	460	87	16	400	2.6E4	8.0E2
ATLANTA	2	2	20				7200	1		1		2	14	1	220	4500	30000	620		55		1100	1.1	220	120	24000	660	350	19	4	330	1.6E8	1.9E4
TULSA	2	2	20				7200	2		1		9		1		43000	91000	1700		37		2000	1.7	112	91	12000	740	340	9	63	240	1.1E6	8.0E5
PHOENIX II	4	2	20				11400	1		1		60		2		11000	58000	3000		130		3200	0.7	141	67	15000	620	490	11	16	210	1.2E5	9.0E3
SEATTLE	5	3	20				11700	1		1		12		1		10000	38000	1100		59		2000	1.1	243	89	29000	2100	460	32	11	480	7.7E5	9.1E3
LOW/OLD/SING	6	0	21				5600	1		1					372	10000	32000	1100		64		2200	2.5	208	110	24000	1500	420	38	26	370	2.1E8	2.3E4
LOW/OLD/MULT	6	0	22				8000	1		1					659	22000	26000	1100		64		2200	3.6	188	90	20000	1900	330	28	19	360	1.5E5	1.2E4
MED/NEW/SING	6	0	23				2500	1		1					418	12000	40000	1100		64		2200	3.3	192	81	18000	1200	420	36	32	290	4.2E5	1.0E4
MED/OLD/SING	6	0	24				1400	1		1								1100		64		2200	2.8	183	94	20000	1600	370	13	18	530		
MED/OLD/MULT	6	0	25				10800	1		1						7100	24000	1100		64		2200	3.1	175	79	24000	1900	330	14	12	350	1.1E8	2.1E4
SAN JOSE I	4	4	21				9400	1	1	1		12		2	70								3.5	325	88	27000	2400	450	95	19	320		
SAN JOSE I	4	4	22				12050	1	2	1		13		2	85								3.5	325	96	23000	2000	450	80	17	370		
SAN JOSE I	4	4	23				300	1	1	1		12		2	24								4.5	295	33	21000	2100	350	100	5	260		
PHOENIX I	4	1	21				2700	1	2	1		12	8	2	77								4.0	203	150	23000	1200	320	0	17	290		
PHOENIX I	4	1	22				11100	1	2	1		12	1	2	238								5.5	159	39	17000	3700	280	0	13	210		
PHOENIX I	4	1	23				10300	1	0	1		12	7	2	18								8.8	215	140	21000	970	680	25	13	330		
PHOENIX I	4	1	25				11000	1	2	1		12	3	2	34								6.0	238	53	23000	3600	440	5	12	490		
MILWAUKEE	1	2	21				14000	1	1	1		0	7	2	103								4.2	130	83	15000	790	280	33	21	300	9.9E4	2.6E1
MILWAUKEE	1	2	22				4000	1	3	4		0	6	2	93								1.4	141	170	14000	580	230	0	24	210		
MILWAUKEE	1	2	23				300	2	1	1		0	7	2	40								0.6	153	120	18000	970	250	26	76	250		
MILWAUKEE	1	2	25				16000	1	2	1		0	9	2	770								2.3	125	72	15000	470	290	18	20	210	8.0E4	
BUCYRUS	1	2	21				300	1	3	1		2		2	950								3.0	132	91	13000	350	420	13	33	190		
BUCYRUS	1	2	23				300	1	0	1		2		2	205								2.6	138	66	15000	430	370	36	33	110		
BUCYRUS	1	2	24				300	1	0	1		2		2	950								1.6	178	94	22000	1600	490	7	41	390		
BALTIMORE	2	2	22				6700	1	1	3		26	1	1	100								8.8	210	120	19000	1700	290	45	24	630		
BALTIMORE	2	2	23				700	2	1	1		26	13	1	67								6.1	290	120	24000	1000	430	55	23	760	1.0E8	
BALTIMORE	2	2	24				700	1	0	1		26	5	1	93								5.5	120	120	15000	730	150	2	5	730		
BALTIMORE	2	2	25				8000	1	0	1		26	4	1	33								5.2	215	190	18000	1500	270	18	6	490		
SAN JOSE II	4	2	21				9400	1	1	1		59		2	11								6.0	295	130	48000	5700	560	120	28	810	5.3E8	2.8E3
SAN JOSE II	4	2	22				12050	1	2	1		59		2	8								2.0	75	34	11000	600	230	30	21	210	1.9E8	1.8E3
SAN JOSE II	4	2	23				300	1	1	1		59		2	3								5.4	265	53	26000	3900	470	75	9	420	9.1E4	3.6E3
ATLANTA	2	2	21				300	1	1	1		2	14	1	295								0.	182	150	24000	280	210	9	3	270	2.0E8	6.8E4
ATLANTA	2	2	22				300	2	1	1		2	1	1	31																	1.3E4	1.2E4
ATLANTA	2	2	23				300	1	1	1		2	21	1	165								0.	127	70	13000	480	280	7	4	180	1.8E8	4.6E3
ATLANTA	2	2	25				300	1	3	1		2	28	1																			
TULSA	2	2	21				5000	1	3	1		9		1	13								1.0	186	160	20000	1100	430	32	78	350	1.4E6	9.3E2
TULSA	2	2	23				700	2	2	1		9		1	69								1.3	150	71	17000	970	520	1	110	180	6.5E5	5.5E2
TULSA	2	2	25				16800	2	2	1		9		1	17								2.4	24	66	1400	230	100	0	6	220	9.4E6	3.4E5
PHOENIX II	4	2	21				2700	1	3	1		60		2	27								1.1	185	99	21000	340	700	11	25	350	2.0E5	1.1E4
PHOENIX II	4	2	22				11100	1		1		60		2	18								0.3	165	74	20000	2000	370	3	23	250	1.9E5	5.6E3
PHOENIX II	4	2	23				10300	1	1	1		60		2	6								0.	111	52	11000	220	450	0	12	130	2.5E4	8.7E4
PHOENIX II	4	2	25				11000	1	2	1		60		2	8								0.8	193	46	25000	2900	420	7	15	290	8.6E4	2.2E3
SEATTLE	5	3	21				6700	1	3	1		12		1	39								0.	233	80	27000	1700	430	39	13	460	1.6E5	3.2E3
SEATTLE	5	3	22				6900	1	1	3		12		1	45								3.4	239	100	37000	3000	490	40	8	660	6.4E4	3.6E4
SEATTLE	5	3	24				3200	2	1	1		12		1	22								1.3	250	67	23000	2500	460	29	9	460		
SEATTLE	5	3	25				12300	1	2	3		12		1	12								1.6	254	48	59000	2600	440	39		410	3.1E5	2.4E2

Table A-7. LAND USE 20 - RESIDENTIAL

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						167000	611000	6670		2720	5390	6670										2.9E6	5.2E5
CINCINNATI	1	4	30	9	20	.37	5600	2	1	1						179000	525000	5050		1810	4940	11880											
CINCINNATI	1	1	30	9	20	.37	5600	2	1	1						[illegible]	423000	1810		1920	1880	6920											
CINCINNATI	1	2	30	9	20	.37	5600	2	1	1						76000	400000	2640		1960	3280	8000											
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						78900	526000	5790		3110	2630	10500											
CINCINNATI	1	0	30	9	20	.37	5600	2		1						76000	489000		4890	4400		9250										1.4E6	8.6E5
TUSCON	4	3	30				14000			1							101000	170		1020												3.4E7	6.2E6
TUSCON	4	1	30				14000			1							147000	230		350												1.9E7	3.8E5
CINCINNATI	1	0	30	9	20	.37	5600	2	1	1					32	109000	457000	4390		2300	3620	8800											
CHICAGO	1	3	30		20		7950		1	4			1	2	134	5060	26700	38		480												3.9E6	9.7E5
CHICAGO	1	3	30		20		20400		1	4			1	2	326	4030	24800	27		323												5.8E5	3.2E4
CHICAGO	1	3	30		20		13500		2	4			1	2	71	14840	66700	142		457												1.0E6	4.0E3
TULSA	2	0	30	4.0	5	.55	10600	2	1	3	.20				46	29300	163000	3200				3600										1.6E6	6.9E4
TULSA	2	0	30	4.3	20	.74	2600	2	1	2	.51				41	25300	247000	1600				1900										3.0E6	7.0E3
CENT.BUS.	6	0	31				15500	1		4					296	8300	30000	1000		600		1600	6.5	247	88	24000	3600	420	46	20	640	1.1E5	1.1E5
SHOP.CENTER	6	0	32				18800	1		4					122	8600	21000	1000		600		1600	3.7	205	250	23000	3400	370	57	16	400	2.0E6	6.8E5
SAN JOSE I	4	4	31				3600	1	2	4		13		2	21								2.6	320	110	16000	3800	470	110	20	600		
SAN JOSE I	4	4	32				13000	1	1	4		18		2	26								5.0	325	80	44000	7400	410	93	10	410		
PHOENIX I	4	1	31				11900	1	2	4		12	1	2	26								6.6	190	69	15000	3200	380	6	15	335		
PHOENIX I	4	1	32				15000	1	1	4		12	13	2	53								2.0	168	25	15000	1600	360	7	11	720		
MILWAUKEE	1	2	31				6000	1	0	4		0	1	2	260								3.9	190	810	25000	2700	300	30	20	680	3.1E4	
MILWAUKEE	1	2	32				20800	2	2	4		0	7	2	30								3.2	177	120	34000	2200	390	37	7	320		
BALTIMORE	2	2	31				14200	1	0	4		26	1	1	5								25.	356	290	40000	5700	770	51	25	1000		
BALTIMORE	2	2	32				27000	1	0	3		26	4	1	4								3.7	264	210	23000	2100	500	7	32	510		
SAN JOSE II	4	2	31				23600	1	2	4		59		2	20								4.9	310	84	30000	5100	500	83	15	510	1.0E4	9.0E3
SAN JOSE II	4	2	32				13000	1	1	4		59		2	3								3.1	430	96	23000	9999	540	140	13	380	6.7E5	6.7E3
ATLANTA	2	2	31				14100	1	1	4		2	1	1	60								5.3	207	300	20000	3900	280	18	13	1100	2.0E5	8.0E2
ATLANTA	2	2	32				34100	1	0	4		2	14	1	215								0.	100	30	12000	2000	290	12	5	320	[illegible]	7.9E3
TULSA	2	2	31				18000	1	2	4		9		1	20								1.6	135	96	11000	1300	250	29	37	420	5.4E5	8.8E5
TULSA	2	2	32				5000	2	2	1		9		1									9.3	63	66	8800	2400	160	10	38	190		
PHOENIX II	4	2	31				11900	1	2	4		60		2	4																	3.9E4	1.1E4
PHOENIX II	4	2	32				15000	1	1	4		60		2	3								6.4	71	99	5000	0	280	170	25	400	4.2E4	1.4E2
SEATTLE	5	3	31				16000	1	2	4		12		1	16								2.3	266	210	32000	3300	430	39	15	500	1.4E5	5.0E2
SEATTLE	5	3	32				26500	1	2	4		12		1	16								1.5	247	63	42000	4700	440	40	0	390	1.8E5	1.0E3

Table A-8. LAND USE 30 - COMMERCIAL

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
GRAND RAPIDS	1	0	40				5600			4													[illegible]	9	16	3100	47		8		57		
TUSCON	4	3	40				12000			4							201000	240		430												1.0E7	1.0E6
TUSCON	4	1	40				12000			4							224000	760		700												3.3E7	4.6E5
TULSA	2	0	40	0.0	10	.46	0	2	1	1	.48				57	39600	222000	2700				1900										2.8E6	5.0E2
LIGHT IND.	6	0	40				8300	1		4					946	15000	73000	1400		72		1600	4.4	288	130	22000	2400	490	44	24	400	3.7E5	6.9E5
SAN JOSE I	4	4	40				7250	1	2	4		13		2	131								3.4	300	47	24000	2000	500	110	0	350		
PHOENIX I	4	1	40				12300	1	1	4		12	10	2	41								11.	208	100	20000	2500	430	6	15	230		
BALTIMORE	2	2	40				9900	1	2	4		26	3	1	87								8.2	760	240	31000	9999	830	37	34	780		
SAN JOSE II	4	2	40				7250	1	2	4		59		2	204								3.7	306	71	17000	2700	490	120	13	340	4.0E4	6.7E1
ATLANTA	2	2	40				5000	1	2	1		2	30	1	1850								1.5	162	140	16000	740	300	19	6	320	8.3E4	5.7E3
TULSA	2	2	40				700	2	1	1		9		1	122								2.8	138	110	15000	1100	440	24	93	360	1.2E5	3.8E1
PHOENIX II	4	2	40				12300	1	1	4		60		2	4								3.1	188	120	24000	2100	460	18	15	360	1.3E5	8.8E1
SEATTLE	5	3	40				10000	2	2	4		12		1	59								1.4	239	110	27000	1100	490	20	16	480	3.1E6	9.1E3

Table A-9. LAND USE 40 - LIGHT INDUSTRY

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	PRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
CHICAGO	1	3	50		20		11140		2	4			1	2	284	2950	23000	30		431												3.2E5	2.7E4
CHICAGO	1	3	50		15		9800		3	1					536	2820	31800	14		410												2.6E6	9.3E5
TULSA	2	0	50	.5	5	.30	10100	1	1	4	.15				419	5800	49000	1600				490										3.2E5	4.2E3
TULSA	2	0	50	3.9	20	.51	10200	1	1	4	.23				88	23200	168000	1800				1400										4.1E5	1.3E6
TULSA	2	0	50	3.2	20	.24	6600	1	2	4	.23				25	35000	267000	9500				1600										4.0E6	5.2E5
MED. IND.	6	0	51				9100	1		4					264	11000	60000	1400		72		1600	3.2	244	47	23000	1400	420	35	24	280	2.3E5	1.3E3
HEAVY IND.	6	0	52				9800	1		4						3700	17000	1400		72		1600	4.7	304	150	40000	470	870	33	17	390	1.2E4	4.9E2
SAN JOSE I	4	4	51				7200	1	1	4		18		2	61								2.2	285	67	26000	3500	600	93	8	450		
PHOENIX I	4	1	51				17200	1	0	4		12	8	2	130								1.7	256	38	24000	1200	330	1	12	210		
MILWAUKEE	1	2	51				12000	1	2	4		0	8	2	51								6.3	179	120	22000	660	270	21	20	370	2.7E4	
MILWAUKEE	1	2	52				8000	1	2	4		0	8	2	1500								1.6	128	170	15000	360	310	30	9	220		
BUCYRUS	1	2	51				300	1	0	1		2		2	500								4.7	335	120	43000	780	620	35	24	200		
BUCYRUS	1	2	52				5000	1	3	4		2		2	800								4.0	159	79	20000	260	470	6	17	140		
BALTIMORE	2	2	51				11000	1	2	4		26	4	1	57								8.8	290	210	25000	1800	680	12	33	410		3.6E3
BALTIMORE	2	2	52				21000	2	0	1		26	4	1	16								6.8	365	150	53000	310	1600	14	38	300		
SAN JOSE II	4	2	51				7200	1	1	4		59		2	19								4.0	194	92	22000	1500	450	93	18	280	5.8E4	6.1E2
ATLANTA	2	2	52				5000	1		1		2	10	1	150								4.4	585	190	72000	940	1100	84	3	880	1.4E5	5.3E2
ATLANTA	2	2	51				5000	1	3	1		2	7	1									7.4	278	38	14000	1400	240	12	14	310		
TULSA	2	2	51				5000	2	2	1		9		1	31								5.4	74	64	8100	65	180	26	77	160	7.3E5	9.1E5
PHOENIX II	4	2	51				17200	1	1	4		60		2	18								0.3	310	32	22000	1700	400	23	10	150	2.3E5	7.2E1

Table A-10. LAND USE 50 - INDUSTRIAL

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	PRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						167000	611000	6670		2720	5390	6670										2.4E6	8.2E5
CINCINNATI	1	4	30	9	20	.37	5600	2	1	1						175000	525000	5090		1810	4940	11880											
CINCINNATI	1	1	30	9	20	.37	5600	2	1	1						46200	423000	1810		1920	1880	6920											
CINCINNATI	1	2	30	9	20	.37	5600	2	1	1						76000	400000	2640		1960	3280	8000											
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						78900	524000	5790		3110	2630	10500											
ANN ARBOR	1	2	20				5600			4						18500		650	2620	650	595	535											
ANN ARBOR	1	3	20				5600			4						30700		950	2770	800	730	365											
ANN ARBOR	1	4	20				5600			4						21300		220	2130	440													
GRAND RAPIDS	1	0	40				5600			4													0.7	9	16	3100	47		8		57		
GRAND RAPIDS	1	0	20				5600			4													0.4	3	8	2200	17		4		21		
GRAND RAPIDS	1	0	10				5600			4													0.6	5	9	2600	15		6		22		
CINCINNATI	1	0	30	9	20	.37	5600	2		1						75000	489000		4850	4400		9250										1.4E6	2.6E5
CINCINNATI	1	0	10	9	20	.37	300	2		1						22300	252000		5440	16000		12800										2.5E5	6.0E3
CINCINNATI	1	0	30	9	20	.37	5600	2	1	1					32	109000	497000	4390		2300	3620	8800											
ANN ARBOR	1	0	20				5600			4					170	23500		610	2510	630	660	450											
CHICAGO	1	3	30		20		7950		1	4			1	2	134	5050	26700	38		480												3.5E6	9.7E5
CHICAGO	1	3	30		20		20400		1	4			1	2	326	4030	24800	27		323												5.8E5	3.2E4
CHICAGO	1	3	30		20		13500		2	4			1	2	71	14840	66700	142		457												1.0E6	4.0E3
CHICAGO	1	3	50		20		11140		2	4			1	2	284	2950	23000	30		431												3.2E5	2.7E4
CHICAGO	1	3	20		10		800		1	1			1	2	19	1720	18300	20		325												1.1E6	1.3E5
CHICAGO	1	3	20		15		1000		2	2			3	2	32	9100	53100	70		523												1.1E6	4.1E4
CHICAGO	1	3	20		50		700		2	4			3	2	121	2180	50700	142		523												1.3E6	7.0E5
CHICAGO	1	3	20		50		1980		3	3			3	2	148	2810	29500	21		773												1.2E6	8.7E5
CHICAGO	1	3	20		20		5860		2	2			3	2	81	4770	61300	63		377												2.6E6	6.1E5
CHICAGO	1	3	20		20		5860		2	2			3	2	62	2900	32600	30		405												1.6E6	1.9E5
CHICAGO	1	3	20		15		1828		2	3			3	2	121	2030	34000	24		845												3.1E6	2.7E5
CHICAGO	1	3	20		20		240		2	3			3	2	135	6320	45600	73		670												5.6E6	4.8E5
CHICAGO	1	3	20		50		14070		1	3			3	2	148	2280	24600	20		961												4.1E6	4.0E5
CHICAGO	1	3	20		20		3600		1	2			7	2	19	3240	24500	24		525												1.0E6	1.2E6
CHICAGO	1	3	20		10		1200		1	2			7	2	20	9430	72800	109		523												3.0E6	1.3E6
CHICAGO	1	3	20		10		17300		2	2			3	2	96	1940	32100	28		482												3.9E5	1.8E4
CHICAGO	1	3	50		15		9800		3	1					536	2820	31800	14		410												2.6E6	9.3E5
CHICAGO	1	3	20		20		1620		2	3			7	2	153	3220	34600	30		356												2.1E6	1.0E6
MILWAUKEE	1	2	20				10100	1		1		0	7	2	2700	4400	18000	100		20		530	2.7	147	160	18000	830	280	22	28	280	4.0E4	8.7E0
BUCYRUS	1	2	20				1200	1		1		2		2	690	2100	21000	180		89		890	2.7	180	90	21000	890	470	17	33	250		
MILWAUKEE	1	2	21				14000	1	1	1		0	7	2	103								4.2	130	83	15000	790	280	33	21	300	9.9E4	8.6E1
MILWAUKEE	1	2	22				4000	1	3	4		0	6	2	93								1.4	141	170	14000	580	230	0	24	210		
MILWAUKEE	1	2	23				300	2	1	1		0	7	2	40								0.6	153	120	18000	970	250	26	76	250		
MILWAUKEE	1	2	25				16000	1	2	1		0	9	2	770								2.3	125	72	15000	470	290	18	20	210	8.0E4	
MILWAUKEE	1	2	31				6000	1	0	4		0	1	2	260								3.9	190	810	25000	2700	300	30	20	650	3.1E4	
MILWAUKEE	1	2	32				20800	2	2	4		0	7	2	30								3.2	177	120	34000	2200	390	37	7	320		
MILWAUKEE	1	2	51				12000	1	2	4		0	8	2	51								6.3	179	120	22000	660	270	21	20	370	2.7E4	
MILWAUKEE	1	2	52				8000	1	2	4		0	8	2	1500								1.6	128	170	15000	360	310	30	9	220		
BUCYRUS	1	2	21				300	1	3	1		2		2	950								3.0	132	91	13000	350	420	13	33	190		
BUCYRUS	1	2	23				300	1	0	1		2		2	205								2.6	138	66	15000	430	370	36	33	110		
BUCYRUS	1	2	24				300	1	0	1		2		2	950								1.6	178	94	22000	1600	490	7	41	390		
BUCYRUS	1	2	51				300	1	0	1		2		2	500								4.7	335	120	43000	780	620	35	24	200		
BUCYRUS	1	2	52				5000	1	3	4		2		2	800								4.0	159	79	20000	260	470	6	17	140		

Table A-11. CLIMATE 1 - NORTHEAST

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FLS	R	S	N	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TOCLI	FOOLI
DURHAM	2	0	20	9.7	10	.29	2900	1	1	1	.20				400	5300	65500		212								117						1.1E5
DURHAM	2	0	20	10.5	10	.34	4200	1	1	1	.24				600												137						
DURHAM	2	0	20	8.2	10	.20	2000	1	1	1	.13				390												66						
TULSA	2	0	50	.5	5	.30	10100	1	1	4	.15				419	5800	49000	1600				490										3.2E5	4.2E3
TULSA	2	0	30	4.0	5	.55	10600	2	1	3	.20				46	23300	163000	3200				3600										1.6E6	6.9E4
TULSA	2	0	20	7.1	5	.27	3800	1	1	1	.19				60	11600	91700	2800				2200										1.9E6	4.8E4
TULSA	2	0	50	3.8	20	.51	10200	1	1	4	.23				98	23200	168000	1800				1600										6.1E5	1.3E4
TULSA	2	0	20	8.9	50	.30	14500	2	2	2	.20				22	67300	510000	3300				2700										5.5E6	5.9E4
TULSA	2	0	50	3.2	20	.24	6600	1	2	4	.23				25	35000	267000	2500				1800										6.0E6	5.2E5
TULSA	2	0	20	11.5	20	.32	8300	2	1	1	.24				32	19000	114000	1600				1900										7.7E5	2.9E3
TULSA	2	0	20	11.3	20	.37	6100	1	1	2	.28				35	39300	298000	3000				1800										6.3E6	1.2E4
TULSA	2	0	20	13.6	20	.31	3800			3	.37				24	24000	277000	2400				1600										9.4E6	7.0E3
TULSA	2	0	30	4.3	20	.74	2600	2	1	2	.51				41	25300	247000	1600				1900										3.0E6	7.0E3
TULSA	2	0	20	9.5	50	.41	3200		3	2	.42				33	25000	207000	1800				1200										6.4E6	1.1E4
TULSA	2	0	40	0.0	10	.46	0	2	1	1	.48				57	39600	222000	2700				1900										2.8E6	8.0E2
TULSA	2	0	20	2.3	10	.23	8000	1	1	1	.20				41	32100	192000	2600				3100										6.0E5	3.8E3
TULSA	2	0	10	.9		.11	0			1	.08				12	18200	90900	1700				1700										8.4E6	6.3E3
TULSA	2	0	20	11.2	20	.38	10200	1	1	2	.22				28	43900	158000	3000				1400										8.1E6	1.3E4
BALTIMORE	2	2	20				10900	1		1		26	4	1	260	61000	20000	1000		38		1900	8.0	273	160	24000	2200	480	31	21	640	1.0E5	
ATLANTA	2	2	20				7200	1		1		2	14	1	220	4800	30000	620		55		1100	1.1	220	120	24000	660	350	19	4	330	1.4E5	1.9E4
TULSA	2	2	20				7200	2		1		9		1		43000	91000	1700		37		2000	1.7	112	91	12000	740	340	9	63	840	1.1E6	8.9E3
BALTIMORE	2	2	22				6700	1	1	3		26	1	1	100								8.8	210	120	19000	1700	290	45	24	630		
BALTIMORE	2	2	23				700	2	1	1		26	13	1	67								6.1	290	120	24000	1000	430	55	23	760	1.0E5	
BALTIMORE	2	2	24				700	1	0	1		26	5	1	93								5.5	120	120	15000	730	150	2	5	730		
BALTIMORE	2	2	25				8000	1	0	1		26	4	1	33								5.2	215	190	18000	1500	270	18	6	490		
BALTIMORE	2	2	31				14200	1	0	4		26	1	1	5								25.	356	290	40000	5700	770	51	25	1000		
BALTIMORE	2	2	32				27000	1	0	3		26	4	1	4								3.7	264	210	23000	2100	500	7	33	510		
BALTIMORE	2	2	40				9900	1	2	4		26	3	1	87								8.2	760	280	31000	9999	830	37	34	780		
BALTIMORE	2	2	51				11000	1	2	4		26	4	1	57								8.8	290	210	25000	1800	680	12	33	410		3.4E3
BALTIMORE	2	2	52				21000	2	0	1		26	4	1	16								6.8	345	150	53000	310	1600	14	38	300		
ATLANTA	2	2	21				300	1	1	1		2	14	1	295								0.	182	150	24000	280	210	9	3	270	2.0E5	6.8E4
ATLANTA	2	2	22				300	2	1	1		2	1	1	31																	1.3E6	1.8E4
ATLANTA	2	2	23				300	1	1	1		2	21	1	165								0.	127	70	13000	480	280	7	4	180	1.0E5	4.6E3
ATLANTA	2	2	31				14100	1	1	4		2	1	1	60								5.3	207	300	20000	3900	280	18	13	1100	2.0E5	9.8E2
ATLANTA	2	2	32				34100	1	0	4		2	14	1	215								0.	100	30	12000	2000	290	12	5	320	1.7E5	7.8E3
ATLANTA	2	2	40				5000	1	2	1		2	30	1	1850								1.5	162	140	16000	740	300	19	6	320	8.3E4	5.7E3
ATLANTA	2	2	52				5000	1		1		2	10	1	150								6.4	585	190	72000	940	1100	84	3	880	1.4E5	6.8E3
ATLANTA	2	2	25				300	1	3	1		7	28	1																			
ATLANTA	2	2	51				5000	1	3	1		2	7	1									0.4	275	38	14000	1400	240	12	14	310		
TULSA	2	2	21				5000	1	3	1		9		1	13								1.0	186	160	20000	1100	430	32	78	380	1.4E6	9.9E3
TULSA	2	2	23				700	2	2	1		9		1	69								1.3	150	71	17000	970	520	1	110	180	6.9E5	5.5E2
TULSA	2	2	25				16800	2	2	1		9		1	17								2.4	24	66	1400	230	100	0	4	820	9.4E6	3.4E3
TULSA	2	2	31				18000	1	2	4		9		1	80								1.6	135	96	11000	1300	250	29	37	420	5.4E5	6.8E3
TULSA	2	2	32				5000	2	2	1		9		1									9.3	63	66	8800	2400	160	10	38	190		
TULSA	2	2	40				700	2	1	1		9		1	122								2.8	138	110	15000	1100	440	24	93	360	1.8E5	3.0E1
TULSA	2	2	51				5000	2	2	1		9		1	31								0.	74	64	8100	65	180	26	77	160	7.3E5	9.1E5

Table A-12. CLIMATE 2 - SOUTHEAST

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
TUSCON	4	3	20				10000			2							200000	520		2730												8.6E7	1.7E7
TUSCON	4	1	20				10000			2							312000	450		940												2.4E7	7.9E5
TUSCON	4	3	30				14000			1							101000	170		1020												3.4E7	8.2E6
TUSCON	4	1	30				14000			1							147000	230		350												1.5E7	3.9E5
TUSCON	4	3	40				12000			4							201000	240		430												1.0E7	1.0E6
TUSCON	4	1	40				12000			4							224000	760		790												3.3E7	4.6E5
SAN JOSE I	4	4	20				10400	1		1		14		2	70	17000	34000	770		3600		2300	3.5	304	71	24000	2700	460	96	8	360		
PHOENIX I	4	1	20				11400	1		1		12	6	2	92	10000	46000	340		450		2300	7.2	211	120	21000	1500	540	15	14	340		
SAN JOSE II	4	2	20				10400	1		1		59		2	860	8900	68000	750		45		1800	4.3	245	75	25000	3400	460	87	16	400	2.6E4	8.0E2
PHOENIX II	4	2	20				11400	1		1		60		2		11000	58000	3000		130		3200	0.7	141	67	15000	620	490	11	16	210	1.2E8	5.8E3
SAN JOSE I	4	4	21				9400	1	1	1		12		2	70								3.5	325	88	27000	2400	450	85	19	320		
SAN JOSE I	4	4	22				12050	1	2	1		13		2	85								3.5	325	96	23000	2000	450	80	17	370		
SAN JOSE I	4	4	23				300	1	1	1		12		2	24								4.5	295	33	21000	2100	350	100	5	260		
SAN JOSE I	4	4	31				3600	1	2	4		13		2	21								2.6	320	110	16000	3500	470	110	20	600		
SAN JOSE I	4	4	32				13000	1	1	4		18		2	26								5.0	325	80	44000	7600	410	93	10	410		
SAN JOSE I	4	4	40				7250	1	2	4		13		2	131								3.4	300	87	24000	2000	500	110	0	350		
SAN JOSE I	4	4	51				7200	1	1	4		18		2	61								2.2	285	67	26000	3500	600	93	8	450		
PHOENIX I	4	1	21				2700	1	2	1		12	8	2	77								4.0	203	150	23000	1200	320	0	17	290		
PHOENIX I	4	1	22				11100	1	2	1		12	1	2	238								5.5	159	39	17000	3700	280	0	13	210		
PHOENIX I	4	1	23				10300	1	0	1		12	7	2	18								8.8	215	140	21000	970	680	25	13	330		
PHOENIX I	4	1	25				11000	1	2	1		12	3	2	34								6.0	238	53	23000	3600	440	5	12	490		
PHOENIX I	4	1	31				11900	1	2	4		12	1	2	26								6.6	190	69	15000	3200	380	6	15	335		
PHOENIX I	4	1	32				15000	1	1	4		12	13	2	53								2.0	168	25	15000	1600	360	7	11	720		
PHOENIX I	4	1	40				12300	1	1	4		12	10	2	41								11.	208	100	20000	[illegible]	430	6	15	230		
PHOENIX I	4	1	51				17200	1	0	4		12	8	2	130								1.7	256	38	24000	[illegible]	330	1	12	210		
SAN JOSE II	4	2	21				9400	1	1	1		59		2	11								6.0	295	130	48000	5700	560	120	28	810	5.3E5	2.8E3
SAN JOSE II	4	2	22				12050	1	2	1		59		2	8								2.0	75	34	11000	600	230	30	21	210	1.9E5	1.5E3
SAN JOSE II	4	2	23				300	1	1	1		59		2	3								5.4	245	53	26000	3900	470	75	9	420	9.1E4	3.6E3
SAN JOSE II	4	2	31				23600	1	2	4		59		2	20								4.9	310	84	30000	5100	500	83	15	510	1.8E4	9.0E2
SAN JOSE II	4	2	32				13000	1	1	4		59		2	3								3.1	430	96	23000	9999	540	140	13	380	6.7E5	6.7E3
SAN JOSE II	4	2	40				7250	1	2	4		59		2	204								3.7	306	71	17000	2700	490	120	13	340	4.0E4	6.7E1
SAN JOSE II	4	2	51				7200	1	1	4		59		2	19								4.0	194	92	22000	1800	450	93	18	280	5.8E4	6.1E2
PHOENIX II	4	2	21				2700	1	3	1		60		2	27								1.1	185	99	21000	340	700	11	25	350	2.0E5	1.1E4
PHOENIX II	4	2	22				11100	1		1		60		2	18								0.3	165	74	20000	2000	370	3	23	250	1.9E5	5.4E3
PHOENIX II	4	2	23				10300	1	1	1		60		2	4								0.	111	52	11000	220	450	0	12	130	2.5E4	2.7E4
PHOENIX II	4	2	25				11000	1	2	1		60		2	8								0.8	193	46	25000	2900	420	7	15	290	8.4E4	2.2E3
PHOENIX II	4	2	31				11900	1	2	4		60		2	4																	3.8E4	1.1E4
PHOENIX II	4	2	32				15000	1	1	4		60		2	3								4.4	71	99	5000	0	280	170	25	400	4.2E4	1.6E2
PHOENIX II	4	2	40				12300	1	1	4		60		2	4								3.1	188	120	24000	2100	440	18	15	360	1.3E5	8.8E1
PHOENIX II	4	2	51				17200	1	1	4		60		2	18								0.3	310	32	22000	1700	400	23	10	180	2.3E5	7.8E1

Table A-13. CLIMATE 4 - SOUTHWEST

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
SEATTLE	5	3	20				11700	1		1		12		1		10000	38000	1100		59		2000	1.1	243	89	29000	2100	460	32	11	480	7.7E5	9.1E3
SEATTLE	5	3	21				6700	1	3	1		12		1	39								0.	233	80	27000	1700	430	39	13	460	1.6E5	3.2E3
SEATTLE	5	3	22				6900	1	1	3		12		1	45								3.4	239	100	37000	3000	490	40	8	660	6.4E4	3.6E4
SEATTLE	5	3	24				3200	2	1	1		12		1	22								1.3	250	67	23000	2500	460	29	9	460		
SEATTLE	5	3	25				12300	1	2	3		12		1	12								1.6	254	48	59000	2600	440	39		410	3.1E5	2.4E2
SEATTLE	5	3	31				16000	1	2	4		12		1	16								2.3	266	210	32000	3300	430	39	15	500	1.6E5	5.0E3
SEATTLE	5	3	32				[illegible]500	1	2	4		12		1	16								1.5	247	63	42000	4700	440	40	0	390	1.8E5	1.8E3
SEATTLE.	5	3	40				10000	2	2	4		12		1	59								1.4	239	110	27000	1100	490	20	16	480	3.1E6	9.1E3

Table A-14. CLIMATE 5 - NORTHWEST

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
CINCINNATI	1	0	10	9	20	.37	300	2		1						22300	252000		5440	16000		12800										2.5E5	8.0E3
CHICAGO	1	3	20		20		240		2	3			3	2	135	6320	45600	73		670												5.6E6	6.8E3
TULSA	2	0	40	0.0	10	.46	0	2	1	1	.48				57	39600	222000	2700				1900										2.8E6	5.0E2
TULSA	2	0	10	.9		.11	0			1	.08				12	18800	90900	1700				1700										8.4E4	6.9E3
SAN JOSE I	4	4	23				300	1	1	1		12		2	24								4.5	295	33	21000	2100	350	100	5	260		
MILWAUKEE	1	2	23				300	2	1	1		0	7	2	40								0.6	153	120	18000	970	250	26	76	250		
BUCYRUS	1	2	21				300	1	3	1		2		2	950								3.0	132	91	13000	350	420	13	33	190		
BUCYRUS	1	2	23				300	1	0	1		2		2	205								2.6	138	66	15000	430	370	36	33	110		
BUCYRUS	1	2	24				300	1	0	1		2		2	950								1.6	178	94	22000	1600	490	7	41	390		
BUCYRUS	1	2	51				300	1	0	1		2		2	500								4.7	335	120	43000	780	620	35	24	200		
SAN JOSE II	4	2	23				300	1	1	1		59		2	3								5.4	245	53	26000	3900	470	75	9	420	9.1E4	3.6E3
ATLANTA	2	2	21				300	1	1	1		2	14	1	295								0.	182	150	24000	280	210	9	3	270	2.0E5	6.8E4
ATLANTA	2	2	22				300	2	1	1		2	1	1	31																	1.3E6	1.8E4
ATLANTA	2	2	23				300	1	1	1		2	21	1	165								0.	127	70	13000	460	260	7	4	180	1.8E5	4.6E3
ATLANTA	2	2	25				300	1	3	1		2	28	1																			

Table A-15. AVERAGE DAILY TRAFFIC - LESS THAN 500

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
DURHAM	2	0	20	9.7	10	.29	2900	1	1	1	.20				400	5300	65500		212								117						1.1E5
DURHAM	2	0	20	10.5	10	.34	4200	1	1	1	.24				600												137						
DURHAM	2	0	20	8.2	10	.20	2000	1	1	1	.13				390												66						
LAWRENCE	3	0	20			.38	2500	1	1	1					210	12900	61600			11600													
CHICAGO	1	3	20		10		800		1	1			1	2	19	1720	18300	20		325												1.1E6	1.3E5
CHICAGO	1	3	20		15		1000		2	2			3	2	32	9100	53100	70		523												1.1E6	4.1E4
CHICAGO	1	3	20		50		700		2	4			3	2	121	2180	50700	142		523												1.3E6	7.0E5
CHICAGO	1	3	20		50		1980		3	3			3	2	148	2810	29500	21		773												1.2E6	8.7E5
CHICAGO	1	3	20		15		1828		2	3			3	2	121	2030	34000	24		845												3.1E6	2.7E5
CHICAGO	1	3	20		20		3600		1	2			7	2	19	3240	24500	24		525												1.0E6	1.2E6
CHICAGO	1	3	20		10		1200		1	2			7	2	20	9430	72800	109		523												3.0E6	1.3E6
CHICAGO	1	3	20		20		1620		2	3			7	2	153	3220	34600	30		356												2.1E6	1.0E6
TULSA	2	0	20	7.1	5	.27	3800	1	1	1	.19				60	11600	91700	2800				2200										1.5E6	4.8E4
TULSA	2	0	20	13.6	20	.31	3800			3	.37				24	24000	277000	2400				1600										9.6E6	7.0E3
TULSA	2	0	30	4.3	20	.74	2600	2	1	2	.51				41	25300	247000	1600				1900										3.0E6	7.0E3
TULSA	2	0	20	9.5	50	.41	3200		3	2	.42				33	25000	207000	1500				1200										6.4E6	1.1E4
BUCYRUS	1	2	20				1200	1		1		2		2	690	2100	21000	180		89		890	2.7	180	90	21000	890	470	17	33	250		
MED/NEW/SING	6	0	23				2500	1		1					418	12000	40000	1100		64		2200	3.3	192	81	18000	1200	420	36	32	290	4.2E5	1.4E4
MED/OLD/SING	6	0	24				1400	1		1								1100		64		2200	2.8	183	94	20000	1600	370	13	18	530		
SAN JOSE I	4	4	31				3600	1	2	4		13		2	21								2.6	320	110	16000	3500	470	110	20	600		
PHOENIX I	4	1	21				2700	1	2	1		12	8	2	77								4.0	203	150	23000	1200	320	0	17	290		
MILWAUKEE	1	2	22				4000	1	3	4		0	6	2	93								1.4	141	170	14000	580	230	0	24	210		
BALTIMORE	2	2	23				700	2	1	1		26	13	1	67								6.1	290	120	24000	1000	430	55	23	760	1.0E5	
BALTIMORE	2	2	24				700	1	0	1		26	5	1	93								5.5	120	120	15000	730	150	2	5	730		
TULSA	2	2	23				700	2	2	1		9		1	69								1.3	150	71	17000	970	520	1	110	180	6.5E5	5.5E2
TULSA	2	2	40				700	2	1	1		9		1	122								2.8	138	110	15000	1100	440	24	93	380	1.2E5	3.8E1
PHOENIX II	4	2	21				2700	1	3	1		60		2	27								1.1	185	99	21000	340	700	11	25	350	2.0E5	1.1E4
SEATTLE	5	3	24				3200	2	1	1		12		1	22								1.3	250	67	23000	2500	460	29	9	460		

Table A-16. AVERAGE DAILY TRAFFIC - 500 to 5000

CITY	C	S	LU	PD	AA	IP	ADT	R	C	A	PRS	R	S	N	LOAD	BOD5	COD	OP04	TP04	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						167000	611000	6670		2720	5390	6670										2.8E6	8.2E5
CINCINNATI	1	4	30	9	20	.37	5600	2	1	1						175000	525000	5050		1810	4940	11880											
CINCINNATI	1	1	30	9	20	.37	5600	2	1	1						46200	423000	1810		1920	1880	6920											
CINCINNATI	1	2	30	9	20	.37	5600	2	1	1						76000	400000	2640		1960	3280	8000											
CINCINNATI	1	3	30	9	20	.37	5600	2	1	1						78900	526000	5790		3110	2630	10500											
ANN ARBOR	1	2	20				5600			4						18500		650	2620	650	594	535											
ANN ARBOR	1	3	20				5600			4						30700		950	2770	800	730	365											
ANN ARBOR	1	4	20				5600			4						21300		220	2130	440													
GRAND RAPIDS	1	0	40				5600			4													0.7	8	16	3100	47		8		57		
GRAND RAPIDS	1	0	20				5600			4													0.4	3	8	2200	17		4		21		
GRAND RAPIDS	1	0	10				5600			4													0.6	5	4	2600	15		6		22		
CINCINNATI	1	0	30	9	20	.37	5600	2		1						75000	489000		4850	4400		9250										1.6E6	2.6E5
TUSCON	4	3	20				10000			2							200000	520		2730												8.6E7	1.7E7
TUSCON	4	1	20				10000			2							312000	450		940												2.4E7	7.9E6
TUSCON	4	3	30				14000			1							101000	170		1020												3.4E7	8.2E6
TUSCON	4	1	30				14000			1							147000	230		350												1.5E7	3.6E5
TUSCON	4	3	40				12000			4							201000	240		430												1.0E7	1.0E6
TUSCON	4	1	40				12000			4							224000	760		700												3.3E7	4.4E5
CINCINNATI	1	0	30	9	20	.37	5600	2	1	1					32	109000	497000	4390		2300	3620	8800											
ANN ARBOR	1	0	20				5600			4					170	23500		610	2510	630	460	450											
CHICAGO	1	3	30		20		7950		1	4			1	2	134	5050	26700	38		480												3.5E6	9.7E5
CHICAGO	1	3	30		20		13500		2	4			1	2	71	14540	66700	142		457												1.0E6	4.0E3
CHICAGO	1	3	50		20		11140		2	4			1	2	284	2950	23000	30		431												3.2E5	2.7E4
CHICAGO	1	3	20		20		5860		2	2			3	2	81	4770	61300	63		377												2.6E6	6.1E5
CHICAGO	1	3	20		20		5860		2	2			3	2	62	2900	32600	30		405												1.0E6	1.9E5
CHICAGO	1	3	20		50		14070		1	3			3	2	148	2280	24600	20		961												4.1E6	4.0E5
CHICAGO	1	3	50		15		9800		3	1					536	2820	31800	14		410												2.6E6	5.3E5
TULSA	2	0	50	.5	5	.30	10100	1	1	4	.15				419	5800	49000	1600				490										3.2E5	4.2E3
TULSA	2	0	30	4.0	5	.55	10600	2	1	3	.20				46	29300	163000	3200				3600										1.6E6	6.9E4
TULSA	2	0	50	3.8	20	.51	10200	1	1	4	.23				88	23200	168000	1800				1600										4.1E5	1.3E4
TULSA	2	0	20	4.9	50	.30	14500	2	2	2	.20				22	67300	510000	3300				2700										5.5E6	5.5E4
TULSA	2	0	50	3.2	20	.24	6600	1	2	4	.23				25	35000	267000	2500				1800										4.0E6	5.2E5
TULSA	2	0	20	11.5	20	.32	8300	2	1	1	.24				32	19000	114000	1600				1900										7.7E5	2.9E3
TULSA	2	0	20	11.3	20	.37	6100	1	1	2	.28				35	39300	298000	3000				1800										6.3E4	1.2E4
TULSA	2	0	20	2.3	10	.23	8000	1	1	1	.20				41	32100	192000	2600				3100										6.0E5	3.8E3
TULSA	2	0	20	11.2	20	.38	10200	1	1	2	.22				28	43900	158000	3000				1400										8.1E4	1.3E4
SAN JOSE I	4	4	20				10400	1		1		14		2	70	17000	34000	770		3600		2300	3.5	304	71	24000	2700	460	96	8	360		
PHOENIX I	4	1	20				11400	1		1		12	6	2	92	10000	46000	340		[illegible]		2300	7.2	211	120	21000	1500	540	15	14	340		
MILWAUKEE	1	2	20				10100	1		1		0	7	2	2700	4400	18000	100		20		530	2.7	167	160	18000	830	280	22	28	280	4.0E4	8.7E0
BALTIMORE	2	2	20				10900	1		1		26	4	1	260	61000	20000	1000		38		1900	8.0	273	160	24000	2200	480	31	21	640	1.0E5	
SAN JOSE II	4	2	20				10400	1		1		59		2	860	8900	68000	750		45		1600	4.3	245	75	25000	3400	460	87	16	400	2.6E4	2.0E2
ATLANTA	2	2	20				7200	1		1		2	14	1	220	4500	30000	620		55		1100	1.1	220	120	24000	660	350	19	4	330	1.6E5	1.8E4
TULSA	2	2	20				7200	2		1		9		1		43000	91000	1700		37		2000	1.7	112	91	12000	740	340	9	63	240	1.1E6	2.5E5
PHOENIX II	4	2	20				11400	1		1		60		2		11000	58000	3000		130		3200	0.7	141	67	15000	620	490	11	16	210	1.2E5	5.8E3
SEATTLE	5	3	20				11700	1		1		12		1		10000	38000	1100		59		2000	1.1	243	89	29000	2100	460	32	11	480	7.7E5	9.1E3
LOW/BLD/SING	6	0	21				5600	1		1					372	10000	32000	1100		64		2200	2.5	208	110	24000	1500	420	38	26	370	2.1E5	2.3E4
LOW/BLD/MULT	6	0	22				8000	1		1					659	22000	26000	1100		64		2200	3.6	188	90	20000	1900	330	28	19	360	1.5E5	1.2E4
MED/BLD/MULT	6	0	25				10800	1		1						7100	24000	1100		64		2200	3.1	175	79	24000	1900	330	14	12	350	1.1E5	2.1E4
LIGHT IND.	6	0	40				8300	1		4					946	15000	73000	1400		72		1600	4.4	288	130	22000	2800	490	44	24	400	3.7E5	6.9E5
MED. IND.	6	0	51				9100	1		4					264	11000	60000	1400		72		1600	3.2	244	87	23000	1400	420	35	24	280	2.3E5	1.3E3
HEAVY IND.	6	0	52				9800	1		4						3700	17000	1400		72		1600	4.7	304	150	40000	470	870	33	17	390	1.2E4	4.5E2
SAN JOSE I	4	4	21				9400	1	1	1		12		2	70								3.5	325	88	27000	2400	450	85	19	320		
SAN JOSE I	4	4	22				12050	1	2	1		13		2	85								3.5	395	96	23000	2000	450	80	17	370		
SAN JOSE I	4	4	32				13000	1	1	4		18		2	26								5.0	325	80	44000	7600	410	93	10	410		
SAN JOSE I	4	4	40				7250	1	2	4		13		2	131								3.4	300	87	24000	2000	500	110	0	350		
SAN JOSE I	4	4	51				7200	1	1	4		18		2	61								2.2	285	67	26000	3500	600	93	8	450		
PHOENIX I	4	1	22				11100	1	2	1		12	1	2	238								5.5	159	39	17000	3700	280	0	13	210		
PHOENIX I	4	1	23				10300	1	0	1		12	7	2	18								8.8	215	140	21000	970	680	25	13	330		
PHOENIX I	4	1	25				11000	1	2	1		12	3	2	34								6.0	238	53	23000	3600	440	5	12	490		
PHOENIX I	4	1	31				11900	1	2	4		12	1	2	26								6.6	190	69	15000	3200	380	6	15	335		
PHOENIX I	4	1	40				12300	1	1	4		12	10	2	41								11.	208	100	20000	2500	430	6	15	230		
MILWAUKEE	1	2	21				14000	1	1	1		0	7	2	103								4.2	130	83	15000	790	280	33	21	300	9.9E4	2.6E1
MILWAUKEE	1	2	31				6000	1	0	4		0	1	2	260								3.9	190	810	25000	2700	300	30	20	650	3.1E4	
MILWAUKEE	1	2	51				12000	1	2	4		0	8	2	51								6.3	179	120	22000	660	270	21	20	370	2.7E4	
MILWAUKEE	1	2	52				8000	1	2	4		0	8	2	1500								1.6	128	170	15000	360	310	30	9	220		
BUCYRUS	1	2	52				5000	1	3	4		2		2	800								4.0	159	79	20000	260	470	6	17	140		
BALTIMORE	2	2	22				6700	1	1	3		26	1	1	100								8.8	210	120	19000	1700	290	45	24	630		
BALTIMORE	2	2	25				8000	1	0	1		26	4	1	33								5.2	215	190	18000	1500	270	18	6	490		
BALTIMORE	2	2	31				14200	1	0	4		26	1	1	5								25.	356	290	40000	5700	770	51	25	1000		
BALTIMORE	2	2	40				9900	1	2	4		26	3	1	87								8.2	760	280	31000	9999	830	37	34	780		
BALTIMORE	2	2	51				11000	1	2	4		26	4	1	57								8.8	290	210	25000	[illegible]	680	12	33	410		3.6E3
SAN JOSE II	4	2	21				9400	1	1	1		59		2	11								6.0	295	130	48000	5700	560	120	28	810	5.3E5	2.9E3
SAN JOSE II	4	2	22				12050	1	2	1		59		2	8								2.0	75	34	11000	600	230	30	21	210	1.9E5	1.9E3
SAN JOSE II	4	2	32				13000	1	1	4		59		2	3								3.1	430	96	23000	9999	540	140	13	380	6.7E5	6.7E3
SAN JOSE II	4	2	40				7250	1	2	4		59		2	204								3.7	306	71	17000	2700	490	120	13	340	4.0E4	6.7E1
SAN JOSE II	4	2	51				7200	1	1	4		59		2	19								4.0	194	72	22000	1500	450	93	18	280	5.8E4	6.1E2
ATLANTA	2	2	31				14100	1	1	4		2	1	1	60								5.3	207	300	20000	3900	280	18	13	1100	2.0E5	2.2E2
ATLANTA	2	2	40				5000	1	2	1		2	30	1	1850								1.5	162	140	16000	740	300	19	6	320	8.3E4	5.7E3
ATLANTA	2	2	52				5000	1		1		2	10	1	150								6.6	585	170	72000	940	1100	84	3	880	1.4E5	5.3E2
ATLANTA	2	2	51				5000	1	3	1		2	7	1									0.4	275	38	14000	1400	240	12	14	310		
TULSA	2	2	21				5000	1	3	1		9		1	13								1.0	186	160	20000	1100	430	32	78	350	1.4E6	9.3E2
TULSA	2	2	32				5000	2	2	1		9		1									9.3	63	66	8800	2400	160	10	38	190		
TULSA	2	2	51				5000	2	2	1		9		1	31								0.	74	64	8100	65	180	26	77	160	7.3E5	9.1E5
PHOENIX II	4	2	22				11100	1		1		60		2	18								0.3	165	74	20000	2000	370	3	23	250	1.9E5	5.4E3
PHOENIX II	4	2	23				10300	1	1	1		60		2	6								0.	111	52	11000	220	450	0	12	130	2.5E4	2.7E4
PHOENIX II	4	2	25				11000	1	2	1		60		2	8								0.8	193	46	25000	2900	420	7	15	290	8.4E4	2.2E3
PHOENIX II	4	2	31				11900	1	2	4		60		2	4																	3.5E4	1.1E6
PHOENIX II	4	2	40				12300	1	1	4		60		2	4								3.1	188	120	24000	2100	460	18	15	360	1.3E5	8.8E1
SEATTLE	5	3	21				6700	1	3	1		12		1	39								0.	233	80	27000	1700	430	39	13	460	1.3E5	3.2E3
SEATTLE	5	3	22				6900	1	1	3		12		1	45								3.4	239	100	37000	3000	490	40	8	660	6.4E4	3.6E4
SEATTLE	5	3	25				12300	1	2	3		12		1	12								1.6	254	48	59000	2600	440	39		410	3.1E5	8.4E2
SEATTLE	5	3	40				10000	2	2	4		12		1	59								1.4	239	110	27000	1100	490	20	16	480	3.1E6	9.1E3

Table A-17. AVERAGE DAILY TRAFFIC - 5000 to 15,000

CITY	C	S	LU	FD	AA	IF	ADT	B	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	CR	ZN	TCOLI	FCOLI
CHICAGO	1	3	30		20		20400		1	4			1	2	326	4030	24800	27		323												5.8E5	3.2E4
CHICAGO	1	3	20		10		17300		2	2			3	2	96	1940	32100	28		482												3.9E5	1.5E4
CENT.BUS.	6	0	31				15500	1		4					296	8300	30000	1000		600		1600	6.5	247	88	24000	3600	420	46	20	640	1.1E5	1.1E5
SHOP.CENTER	6	0	32				18800	1		4					122	8600	21000	1000		600		1600	3.7	205	250	23000	3600	370	57	16	400	2.0E6	8.2E5
PHOENIX I	4	1	32				15000	1	1	4		12	13	2	53								2.0	168	25	15000	1600	360	7	11	720		
PHOENIX I	4	1	51				17200	1	0	4		12	8	2	130								1.7	256	38	24000	1200	330	1	12	210		
MILWAUKEE	1	2	25				16000	1	2	1		0	9	2	770								2.3	125	72	15000	470	290	18	20	210	8.0E4	
MILWAUKEE	1	2	32				20800	2	2	4		0	7	2	30								3.2	177	120	34000	2200	390	37	7	320		
BALTIMORE	2	2	32				27000	1	0	3		26	4	1	4								3.7	264	210	23000	2100	500	7	33	510		
BALTIMORE	2	2	52				21000	2	0	1		26	4	1	16								6.8	345	150	53000	310	1600	14	38	300		
SAN JOSE II	4	2	31				23600	1	2	4		59		2	20								4.9	310	84	30000	5100	500	83	[illegible]	510	1.8E4	9.0E2
ATLANTA	2	2	32				34100	1	0	4		2	14	1	215								0.	100	30	12000	2000	290	12	[illegible]	320	1.7E5	7.8E3
TULSA	2	2	25				16800	2	2	1		9		1	17								2.4	24	66	1400	230	100	0	6	220	9.4E6	3.4E5
TULSA	2	2	31				18000	1	2	4		9		1	20								1.6	135	96	11000	1300	250	29	37	420	5.6E5	5.2E5
PHOENIX II	4	2	32				15000	1	1	4		60		2	3								6.4	71	99	5000	0	280	170	25	400	4.2E4	1.4E2
PHOENIX II	4	2	51				17200	1	1	4		60		2	18								0.3	310	32	22000	1700	400	23	10	150	2.3E5	7.8E1
SEATTLE	5	3	31				16000	1	2	4		12		1	16								2.3	266	210	32000	3300	430	39	15	500	1.6E5	5.0E3
SEATTLE	5	3	32				26500	1	2	4		12		1	16								1.5	247	63	42000	4700	440	40	0	390	1.8E5	1.8E3

Table A-18. AVERAGE DAILY TRAFFIC - GREATER THAN 15,000

CITY	C	S	LU	FD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TOOLI	FOOLI
DURHAM	2	0	20	9·7	10	·29	2900	1	1	1	·20				400	6300	65500		212								117						1·1E8
DURHAM	2	0	20	10·5	10	·34	4200	1	1	1	·24				600												137						
DURHAM	2	0	20	8·2	10	·20	2000	1	1	1	·13				390												66						
LAWRENCE	3	0	20			·38	2500	1	1	1					210	18900	61600			11600													
CINCINNATI	1	3	30	9	20	·37	5600	2	1	1						167000	611000	6670		2720	5390	6670										2·8E6	8·8E8
CINCINNATI	1	4	30	9	20	·37	5600	2	1	1						175000	525000	8050		1810	4940	11880											
CINCINNATI	1	1	30	9	20	·37	5600	2	1	1						46800	423000	1810		1920	1880	6920											
CINCINNATI	1	2	30	9	20	·37	5600	2	1	1						76000	400000	2640		1960	3280	8000											
CINCINNATI	1	3	30	9	20	·37	5600	2	1	1						78900	526000	5790		3110	2630	10500											
CINCINNATI	1	0	30	9	20	·37	5600	2		1						78000	489000		4880	4400		9250										1·6E6	2·6E8
CINCINNATI	1	0	10	9	20	·37	[illegible]00	2		1						28300	252000		5440	16000		12800										2·5E8	8·0E3
TUSCON	4	3	30				14000			1							101000	170		1020												3·4E7	8·8E6
TUSCON	4	1	30				14000			1							147000	230		350												1·5E7	3·8E5
CINCINNATI	1	0	30	9	20	·37	5600	2	1	1					32	109000	497000	4390		2300	3620	8800											
CHICAGO	1	3	20		10		800		1	1			1	2	19	1720	18300	80		325												1·1E6	1·3E8
CHICAGO	1	3	50		15		9800		3	1					536	2820	31800	14		410												2·6E6	8·3E8
TULSA	2	0	20	7·1	5	·27	3800	1	1	1	·19				60	11600	91700	2800				2200										1·5E6	6·8E4
TULSA	2	0	20	11·5	20	·32	8300	2	1	1	·24				32	19000	114000	1600				1900										7·7E5	2·9E3
TULSA	2	0	40	0·0	10	·46	0	2	1	1	·48				57	39600	222000	2700				1900										2·8E6	8·0E2
TULSA	2	0	20	2·3	10	·23	8000	1	1	1	·20				41	32100	192000	2600				3100										6·0E5	3·8E3
TULSA	2	0	10	·9		·11	0			1	·08				12	18200	90900	1700				1700										8·4E4	6·3E3
SAN JOSE I	4	4	20				10400			1		14		2	70	17000	34000	770		3600		2300	3·5	304	71	24000	2700	460	96	8	360		
PHOENIX I	4	1	20				11400	1		1		12	6	2	92	10000	46000	340		450		2300	7·2	211	120	21000	1500	540	15	14	340		
MILWAUKEE	1	2	20				10100	1		1		0	7	2	2700	4400	18000	100		20		530	2·7	147	160	18000	830	280	22	28	280	4·0E4	8·7E0
BUCYRUS	1	2	20				1200	1		1		2		2	690	2100	21000	180		89		890	2·7	180	90	21000	890	470	17	33	250		
BALTIMORE	2	2	20				10900	1		1		26	4	1	260	61000	20000	1000		38		1900	8·0	273	160	24000	2200	480	31	21	640	1·0E5	
SAN JOSE II	4	2	20				10400	1		1		59		2	860	8900	68000	750		45		1800	4·3	245	75	25000	3400	460	87	16	400	2·6E4	2·0E2
ATLANTA	2	2	20				7200	1		1		2	14	1	220	4800	30000	620		55		1100	1·1	220	120	24000	660	350	19	4	330	1·6E5	1·8E4
TULSA	2	2	20				7200	2		1		9		1		43000	91000	1700		37		2000	1·7	112	91	12000	740	340	9	63	260	1·1E6	8·8E5
PHOENIX II	4	2	20				11400	1		1		60		2		11000	58000	3000		130		3200	0·7	141	67	15000	620	490	11	16	210	1·8E5	8·8E3
SEATTLE	5	3	20				11700	1		1		12		1		10000	38000	1100		59		2000	1·1	243	89	29000	2100	460	32	11	480	7·7E5	9·1E3
LOW/OLD/SING	6	0	21				5600	1		1					372	10000	32000	1100		64		2200	2·5	208	110	24000	1500	420	38	26	370	2·1E5	8·3E4
LOW/OLD/MULT	6	0	22				8000	1		1					659	22000	26000	1100		64		2200	3·6	188	90	20000	1900	330	28	19	360	1·5E5	1·8E4
MED/NEW/SING	6	0	23				2600	1		1					418	12000	40000	1100		64		2200	3·3	192	81	18000	1200	420	36	32	290	4·2E5	1·4E4
MED/OLD/SING	6	0	24				1400	1		1								1100		64		2200	2·8	183	94	20000	1600	370	13	18	530		
MED/OLD/MULT	6	0	25				10800	1		1						7100	24000	1100		64		2200	3·1	175	79	24000	1900	330	14	12	350	1·1E5	8·1E4
SAN JOSE I	4	4	21				9400	1	1	1		12		2	70								3·5	325	88	27000	2400	450	85	19	320		
SAN JOSE I	4	4	22				12050	1	2	1		13		2	85								3·5	325	96	23000	2000	450	80	17	370		
SAN JOSE I	4	4	23				300	1	1	1		12		2	84								4·5	295	33	21000	2100	350	100	8	260		
PHOENIX I	4	1	21				2700	1	2	1		12	8	2	77								4·0	203	150	23000	1800	320	0	17	290		
PHOENIX I	4	1	22				11100	1	2	1		12	1	2	238								5·5	159	39	17000	3700	280	0	13	210		
PHOENIX I	4	1	23				10300	1	0	1		12	7	2	18								8·8	215	140	21000	970	680	25	13	330		
PHOENIX I	4	1	25				11000	1	2	1		12	3	2	34								6·0	238	53	23000	3600	440	5	12	490		
MILWAUKEE	1	2	21				14000	1	1	1		0	7	2	103								4·2	130	83	15000	790	280	33	21	300	9·9E4	2·6E1
MILWAUKEE	1	2	23				300	2	1	1		0	7	2	40								0·6	153	120	18000	970	250	26	76	250		
MILWAUKEE	1	2	25				16000	1	2	1		0	9	2	770								2·3	125	72	15000	470	290	18	20	210	8·0E4	
BUCYRUS	1	2	21				300	1	3	1		2		2	950								3·0	132	91	13000	350	420	13	33	190		
BUCYRUS	1	2	23				300	1	0	1		2		2	205								2·6	138	66	15000	430	370	36	33	110		
BUCYRUS	1	2	24				300	1	0	1		2		2	950								1·6	178	94	22000	1600	490	7	41	390		
BUCYRUS	1	2	51				300	1	0	1		2		2	500								4·7	335	120	43000	780	620	35	24	200		
BALTIMORE	2	2	23				700	2	1	1		26	13	1	67								6·1	290	120	24000	1000	430	55	23	760	1·0E5	
BALTIMORE	2	2	24				700	1	0	1		26	5	1	93								5·5	120	120	15000	730	150	2	5	730		
BALTIMORE	2	2	25				8000	1	0	1		26	4	1	33								5·2	215	190	18000	1500	270	18	6	490		
BALTIMORE	2	2	52				21000	2	0	1		26	4	1	16								6·8	345	150	53000	310	1600	14	38	300		
SAN JOSE II	4	2	21				9400	1	1	1		59		2	11								6·0	295	130	48000	5700	560	120	28	810	5·3E5	8·8E2
SAN JOSE II	4	2	22				12050	1	8	1		59		2	8								2·0	75	34	11000	600	230	30	21	210	1·9E5	1·8E3
SAN JOSE II	4	2	23				300	1	1	1		59		2	3								5·4	245	53	26000	3900	470	75	9	420	9·1E4	3·6E2
ATLANTA	2	2	21				300	1	1	1		2	14	1	295								0·	182	150	24000	280	210	9	3	270	2·0E5	6·8E4
ATLANTA	2	2	22				300	2	1	1		2	1	1	31																	1·3E4	1·2E4
ATLANTA	2	2	23				300	1	1	1		2	21	1	168								0·	127	70	13000	480	280	7	4	180	1·8E5	6·6E3
ATLANTA	2	2	40				5000	1	2	1		2	30	1	1850								1·5	162	140	16000	740	300	19	6	320	8·3E4	8·7E3
ATLANTA	2	2	52				5000	1		1		2	10	1	150								6·4	585	190	72000	940	1100	84	3	880	1·4E5	8·3E2
ATLANTA	2	2	25				300	1	3	1		2	28	1																			
ATLANTA	2	2	51				5000	1	3	1		2	7	1									0·4	275	38	14000	1400	240	12	14	310		
TULSA	2	2	21				5000	1	3	1		9		1	13								1·0	186	160	20000	1100	430	32	78	390	1·4E6	9·3E2
TULSA	2	2	23				700	2	2	1		9		1	69								1·3	150	71	17000	970	920	1	110	180	6·5E5	9·8E2
TULSA	2	2	25				16800	2	2	1		9		1	17								2·4	24	66	1400	230	100	0	6	220	9·4E6	3·6E5
TULSA	2	2	32				5000	2	2	1		9		1									9·3	63	66	8800	2400	160	10	38	190		
TULSA	2	2	40				700	2	1	1		9		1	122								2·8	138	110	15000	1100	440	24	93	360	1·2E5	3·8E1
TULSA	2	2	51				5000	2	2	1		9		1	31								0·	74	64	8100	65	180	26	77	160	7·3E5	9·1E0
PHOENIX II	4	2	21				2700	1	3	1		60		2	27								1·1	185	99	21000	340	700	11	25	350	2·0E5	1·1E4
PHOENIX II	4	2	22				11100	1		1		60		2	18								0·3	165	74	20000	2000	370	3	23	250	1·9E5	8·4E3
PHOENIX II	4	2	23				10300	1	1	1		60		2	6								0·	111	52	11000	220	450	0	12	130	2·5E4	8·7E0
PHOENIX II	4	2	25				11000	1	2	1		60		2	8								0·8	193	46	25000	2900	420	7	15	290	8·6E4	8·8E3
SEATTLE	5	3	21				6700	1	3	1		12		1	39								0·	233	80	27000	1700	430	39	13	460	1·6E5	3·2E3
SEATTLE	5	3	24				3200	2	1	1		12		1	22								1·3	250	67	23000	2500	460	29	9	460		

Table A-19. LANDSCAPING BEYOND THE SIDEWALK 1 - GRASS

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
TUSCON	4	3	20				10000			2							200000	520		2730												8.6E7	1.7E7
TUSCON	4	1	20				10000			2							312000	450		940												2.4E7	7.0E5
CHICAGO	1	3	20		15		1000		2	2			3	2	32	9100	53100	70		523												1.1E6	4.1E4
CHICAGO	1	3	20		20		5860		2	2			3	2	81	4770	61300	63		377												2.6E6	6.1E5
CHICAGO	1	3	20		20		5860		2	2			3	2	62	2900	32600	30		405												1.6E6	1.9E5
CHICAGO	1	3	20		20		3600		1	2			7	2	19	3840	24500	24		525												1.0E6	1.2E6
CHICAGO	1	3	20		10		1200		1	2			7	2	20	9430	72800	109		523												3.0E6	1.3E6
CHICAGO	1	3	20		10		17300		2	2			3	2	96	1940	32100	28		482												3.9E5	1.9E4
TULSA	2	0	20	8.9	50	.30	14500	2	2	2	.20				22	67300	510000	3300				2700										5.5E6	6.9E4
TULSA	2	0	20	11.3	20	.37	6100	1	1	2	.28				35	39300	298000	3000				1800										6.3E6	1.2E4
TULSA	2	0	30	4.3	20	.74	2600	2	1	2	.51				41	25300	247000	1600				1900										3.0E6	7.0E3
TULSA	2	0	20	9.5	50	.41	3200		3	2	.42				33	25000	207000	1500				1200										6.4E6	1.1E4
TULSA	2	0	20	11.2	20	.38	10200	1	1	2	.22				28	43900	158000	3000				1400										8.1E6	1.9E4

Table A-20. LANDSCAPING BEYOND THE SIDEWALK 2 - TREES

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	R	S	M	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
CHICAGO	1	3	20		50		1980		3	3			3	2	148	2810	29500	21		773												1.2E6	5.7E5
CHICAGO	1	3	20		15		1828		2	3			3	2	121	2030	34000	24		845												3.1E6	2.7E5
CHICAGO	1	3	20		20		240		2	3			3	2	135	6320	45600	73		670												5.6E6	4.5E5
CHICAGO	1	3	20		50		14070		1	3			3	2	148	2280	24600	20		961												4.1E6	4.0E5
CHICAGO	1	3	20		20		1620		2	3			7	2	153	3220	34600	30		356												2.1E6	1.0E6
TULSA	2	0	30	4.0	5	.55	10600	2	1	3	.20				46	29300	163000	3200				3600										1.6E6	6.9E4
TULSA	2	0	20	13.6	20	.31	3800			3	.37				24	24000	277000	2400				1600										9.6E6	7.0E3
BALTIMORE	2	2	22				6700	1	1	3		26	1	1	100								9.8	210	120	19000	1700	290	45	24	630		
BALTIMORE	2	2	32				27000	1	0	3		26	4	1	4								3.7	264	210	23000	2100	500	7	33	510		
SEATTLE	5	3	22				6900	1	1	3		12		1	45								3.4	239	100	37000	3000	490	40	8	660	6.4E4	5.6E4
SEATTLE	5	3	25				12300	1	2	3		12		1	12								1.6	254	48	59000	2600	440	39		410	3.1E8	2.4E2

Table A-21. LANDSCAPING BEYOND THE SIDEWALK 3 - LANDSCAPED BUILDINGS

CITY	C	S	LU	PD	AA	IF	ADT	S	C	A	FRS	E	S	N	LOAD	BOD5	COD	OPO4	TPO4	NO3	NH4	ORGN	CD	CR	CU	FE	PB	MN	NI	SR	ZN	TCOLI	FCOLI
ANN ARBOR	1	2	20				5600			4						18800		650	2620	650	595	535											
ANN ARBOR	1	3	20				5600			4						30700		950	2770	800	730	365											
ANN ARBOR	1	4	20				5600			4						21300		280	2130	440													
GRAND RAPIDS	1	0	40				5600			4													0.7	9	16	3100	47		8		57		
GRAND RAPIDS	1	0	20				5600			4													0.4	3	8	2200	17		4		21		
GRAND RAPIDS	1	0	10				5600			4													0.6	5	9	2600	15		6		22		
TUSCON	4	3	40				12000			4							201000	240		430												1.0E7	1.0E6
TUSCON	4	1	40				12000			4							224000	760		790												3.3E7	4.6E5
ANN ARBOR	1	0	20				5600			4					170	23800		610	2510	630	660	450											
CHICAGO	1	3	30		20		7950		1	4			1	2	134	5050	26700	38		480												3.9E6	9.7E5
CHICAGO	1	3	30		20		20400		1	4			1	2	326	4030	24800	27		323												5.8E5	3.8E4
CHICAGO	1	3	30		20		13500		2	4			1	2	71	14540	66700	162		457												1.0E6	4.0E3
CHICAGO	1	3	50		20		11140		2	4			1	2	284	2950	23000	30		431												3.2E5	2.7E4
CHICAGO	1	3	20		50		700		2	4			3	2	121	2180	50700	162		523												1.3E6	7.0E5
TULSA	2	0	50	.5	5	.30	10100	1	1	4	.15				419	5800	49000	1600				490										3.2E5	4.8E3
TULSA	2	0	50	3.8	20	.51	10200	1	1	4	.23				88	23200	168000	1800				1600										4.1E5	1.3E4
TULSA	2	0	50	3.2	20	.24	6600	1	2	4	.23				85	35000	267000	2500				1800										4.0E6	8.8E5
CENT.BUS.	6	0	31				15500	1		4					296	8300	30000	1000		600		1600	6.5	247	88	24000	3600	420	46	20	640	1.1E5	1.1E5
SHOP.CENTER	6	0	32				18800	1		4					122	8600	21000	1000		600		1600	3.7	205	250	23000	3600	370	57	16	400	2.0E6	5.2E5
LIGHT IND.	6	0	40				8300	1		4					946	18000	73000	1400		72		1600	4.4	288	130	22000	2800	490	44	24	400	3.7E5	6.9E5
MED. IND.	6	0	51				9100	1		4					264	11000	60000	1400		72		1600	3.2	244	87	23000	1400	420	35	24	280	2.3E5	1.3E3
HEAVY IND.	6	0	52				9800	1		4						3700	17000	1400		72		1600	4.7	304	150	40000	470	870	33	17	390	1.2E4	4.5E2
SAN JOSE I	4	4	31				3600	1	2	4		13		2	21								2.6	320	110	16000	3800	470	110	20	600		
SAN JOSE I	4	4	32				13000	1	1	4		18		2	26								5.0	325	80	44000	7600	410	93	10	410		
SAN JOSE I	4	4	40				7250	1	2	4		13		2	131								3.4	300	87	24000	2000	500	110	0	350		
SAN JOSE I	4	4	51				7200	1	1	4		18		2	61								2.2	285	67	26000	3800	600	93	8	450		
PHOENIX I	4	1	31				11900	1	2	4		12	1	2	26								6.6	190	69	15000	3200	380	6	15	335		
PHOENIX I	4	1	32				15000	1	1	4		12	13	2	53								2.0	168	25	15000	1600	360	7	11	720		
PHOENIX I	4	1	40				12300	1	1	4		12	10	2	41								11.	208	100	20000	2500	430	6	15	230		
PHOENIX I	4	1	51				17200	1	0	4		12	8	2	130								1.7	256	38	24000	1200	330	1	12	210		
MILWAUKEE	1	2	22				4000	1	3	4		0	6	2	93								1.4	141	170	14000	580	230	0	24	210		
MILWAUKEE	1	2	31				6000	1	0	4		0	1	2	260								3.9	190	810	25000	2700	300	30	20	650	3.1E4	
MILWAUKEE	1	2	32				20800	2	2	4		0	7	2	30								3.2	177	120	34000	2200	390	37	7	320		
MILWAUKEE	1	2	51				12000	1	2	4		0	8	2	51								6.3	179	120	22000	660	270	21	20	370	2.7E4	
MILWAUKEE	1	2	52				8000	1	2	4		0	8	2	1500								1.6	128	170	18000	360	310	30	9	220		
BUCYRUS	1	2	52				5000	1	3	4		2		2	800								4.0	159	79	20000	260	470	6	17	140		
BALTIMORE	2	2	31				14200	1	0	4		26	1	1	5								25.	356	290	40000	5700	770	51	25	1000		
BALTIMORE	2	2	40				9900	1	2	4		26	3	1	87								8.2	760	280	31000	9999	830	37	34	780		
BALTIMORE	2	2	51				11000	1	2	4		26	4	1	57								8.8	290	210	25000	1800	680	12	32	910		3.0E3
SAN JOSE II	4	2	31				23600	1	2	4		59		2	20								4.9	310	84	30000	6100	500	83	15	510	1.0E6	3.0E3
SAN JOSE II	4	2	32				13000	1	1	4		59		2	3								3.1	430	96	23000	9999	540	140	13	380	6.7E5	6.7E3
SAN JOSE II	4	2	40				7250	1	2	4		59		2	204								3.7	306	71	17000	2700	490	120	13	340	4.0E4	6.7E1
SAN JOSE II	4	2	51				7200	1	1	4		59		2	19								4.0	194	92	22000	1500	450	93	18	280	8.8E4	6.1E3
ATLANTA	2	2	31				14100	1	1	4		2	1	1	60								5.3	207	300	20000	3900	280	18	13	1100	2.0E5	8.8E2
ATLANTA	2	2	32				34100	1	0	4		2	14	1	215								0.	100	30	12000	2000	290	12	5	320	1.7E5	7.8E3
TULSA	2	2	31				18000	1	2	4		9		1	20								1.6	135	96	11000	1300	250	29	37	420	5.6E5	5.8E3
PHOENIX II	4	2	31				11900	1	2	4		60		2	4																	3.9E4	1.1E4
PHOENIX II	4	2	32				15000	1	1	4		60		2	3								6.4	71	99	5000	0	280	170	25	400	4.2E4	1.6E2
PHOENIX II	4	2	40				12300	1	1	4		60		2	4								3.1	188	120	24000	2100	460	18	15	360	1.3E5	8.8E1
PHOENIX II	4	2	51				17200	1	1	4		60		2	18								0.3	310	32	22000	1700	400	23	10	150	2.3E5	7.8E1
SEATTLE	5	3	31				16000	1	2	4		12		1	16								2.3	266	210	32000	3300	430	39	15	500	1.6E5	8.0E3
SEATTLE	5	3	32				26500	1	2	4		12		1	16								1.5	247	63	42000	4700	440	40	0	390	1.8E5	1.8E3
SEATTLE	5	3	40				10000	2	2	4		12		1	55								1.4	239	110	27000	1100	490	20	16	460	3.1E6	9.1E3

Table A-22. LANDSCAPING BEYOND THE SIDEWALK 4 - NO LANDSCAPING

Table A-23. THE BASIC STATISTICS OF THE AVAILABLE DATA, INCLUDING THE MEAN ($\overline{X}$), STANDARD DEVIATION (σ), RANGE (R), AND NUMBER OF SAMPLES (N) IN THE SET OF ALL DATA AND IN 19 SUBSETS OF THE DATA[a]

			lbs/curb mi/day	Concentrations in Micrograms per Gram of Dry Solids																No./gram	
Category	#		Loading	BOD$_5$	COD	OPO$_4$	TPO$_4$	NO$_3$	NH$_4$	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TColi[b]	FColi[b]
LAND USE	10	$\overline{X}$	12	20,300	171,000	1,700	5,440	16,000	-	7,250	6.6	5	9	2,600	15	-	6	-	22	1.0E5	7.1E3
		σ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		R	-	18,200- 22,300	91,000- 252,000	-	-	-	-	1,700- 12,800	- 	- 	-	-	-	-	-	-	-	.8 - 2.3E5	6.3 - 8.0E3
		N	1	2	2	1	1	1		2	1	1	1	1	1		1		1	2	2
	20	$\overline{X}$	149	14,000	82,000	850	2,000	550	660	1,800	3.0	192	93	20,600	1,430	392	28	21	350	1.7E6	1.6E5
		σ	195	11,900	81,800	904	1,050	742	-	774	2.2	63	37	7,020	1,030	120	27	16	152	2.5E6	2.0E5
		R	8- 770	2,100- 43,900	18,300- 298,000	21- 3,000	212- 2,770	37- 3,600	595- 730	365- 3,100	0- 8.0	75- 325	34- 160	2,200- 48,000	66- 3,900	100- 700	0- 100	4- 78	130- 760	4.0E4- 9.6E6	2.0E2- 1.2E6
		N	65	37	35	38	5	33	3	26	48	48	48	48	51	49	48	46	48	49	48
	30	$\overline{X}$	74	58,700	269,000	2,250	4,850	1,580	3,620	6,430	4.2	225	133	23,300	3,440	397	48	18	520	1.0E6	1.9E5
		σ	97	58,000	220,000	2,270	-	1,250	1,360	3,710	2.1	98	83	11,400	1,620	130	38	9	230	3.4E6	2.0E5
		R	3- 326	4,030- 175,000	24,800- 611,000	27- 6,670		323- 4,400	1,880- 5,390	1,600- 11,880	1.5- 9.3	63- 430	63- 300	5,000- 42,000	1,300- 7,600	160- 770	7- 140	5- 37	190- 1,100	3.1E4- 1.5E7	2.2E2- 9.7E5
		N	25	14	16	15	1	14	6	11	17	19	17	19	17	19	17	17	19	19	20
	40	$\overline{X}$	389	27,300	180,000	1,275	-	430	-	1,750	4.0	280	128	21,800	2,760	490	41	27	368	2.1E6	1.3E5
		σ	617	-	-	-	-	-	-	-	3.2	187	61	5,300	2,810	140	41	28	183	3.4E6	2.7E5
		R	41- 1,850	15,000- 39,600	73,000- 224,000	240- 2,700	-	72- 790	-	1,600- 1,900	0.7- 11.0	130- 760	71- 280	15,000- 31,000	740- 9,999	300- 500	6- 120	6- 93	57- 480	4.0E4- 1.0E7	3.0E1- 6.9E5
		N	9	2	4	4	-	3	-	2	10	9	9	9	9	9	10	8	10	8	8
	50	$\overline{X}$	203	12,100	88,000	1,250	-	246	-	1,620	3.9	278	107	28,600	1,160	570	37	23	317	8.2E5	1.0E5
		σ	232	12,400	94,100	920	-	201	-	530	2.6	110	57	16,700	855	378	30	18	184	1.3E6	3.2E5
		R	16- 800	2,850- 35,000	17,000- 267,000	14- 2,500	-	72- 431	-	490- 1,800	0.3- 8.8	120- 585	32- 210	8,100- 72,000	260- 3,500	180- 1,600	6- 93	8- 77	140- 880	2.7E4 2.6E6	4.5E2 9.1E5
		N	17	7	7	7	-	4	-	5	14	16	15	15	16	15	14	16	15	11	11
CLIMATE	1	$\overline{X}$	291	29,100	159,000	999	3,390	1,010	2,640	5,970	2.6	139	99	17,700	870	363	21	27	260	1.0E6	4.4E5
		σ	353	46,300	205,000	1,900	1,390	1,000	1,820	4,770	1.6	77	67	10,200	718	112	12	16	137	1.4E6	4.1E5
		R	19- 1,500	1,720- 175,000	18,000- 611,000	14- 6,670	2,130- 5,440	89- 6,400	595- 5,390	365- 12,800	0.4 6.3	5- 335	9- 170	8,100- 43,000	47- 2,700	230- 620	4- 36	7- 41	57- 650	8.0E4- 5.6E6	8.0E3- 1.3E6
		N	33	32	28	30	6	30	9	13	18	19	18	18	16	15	17	15	18	26	21
	2	$\overline{X}$	103	29,100	172,000	1,240	212	43	-	1,970	4.0	234	137	20,300	1,370	395	21	28	439	1.9E6	7.0E4
		σ	113	17,500	119,000	710	-	-	-	640	3.2	156	66	10,000	1,230	240	15	26	240	2.6E6	1.4E5
		R	12- 419	4,500- 67,300	20,000- 510,000	1,000- 3,300	-	37- 55	-	1,100- 3,600	0 - 9.3	63- 585	38- 290	8,100- 53,000	117- 5,700	100- 1,100	1- 55	3- 93	160- 1,000	8.4E4- 9.4E6	2.7E2- 5.2E5
		N	38	19	19	17	1	3	-	17	24	25	24	24	26	25	24	24	25	30	31
	4	$\overline{X}$	50	11,700	139,000	470	-	1,160	-	2,400	3.8	241	78	22,600	2,520	446	57	13	357	5.7E6	3.2E5
		σ	58	3,620	92,800	243	-	1,190	-	580	2.1	77	33	7,600	1,620	104	51	5	147	1.1E7	1.0E6
		R	3- 238	8,900- 17,000	34,000- 312,000	170- 750	-	130- 2,730	-	1,800- 3,200	0.3- 8.8	75- 325	25- 130	11,000- 48,000	220- 7,600	200- 700	0- 140	5- 28	130- 720	2.5E4- 3.4E7	7.2E1- 8.2E6
		N	31	4	10	9	-	9	-	4	31	32	33	32	31	33	32	29	33	31	21
	5	$\overline{X}$	30	10,000	38,000	1,100	-	39	-	2,000	1.8	246	96	34,500	2,600	455	35	10	480	6.0E5	1.1E4
		σ	18	-	-	-	-	-	-	-	0.8	10	30	11,600	1,090	25	7	5	82	11.0E5	1.2E4
		R	12- 59	-	-	-	-	-	-	-	1.1- 3.4	233 266	40- 210	23,000- 39,000	1,100- 4,700	430- 490	20- 60	0- 16	390- 660	6.4E4- 3.1E6	1.5E3- 3.0E4
		N	7	1	1	1	-	1	-	1	7	8	8	8	8	8	8	7	8	7	6

Table A-23 (continued)

Category	#		lbs/curb mi/day	Concentrations in Micrograms per Gram of Dry Solids																No./gram	
			Loading	BOD_5	COD	OPO_4	TPO_4	NO_3	NH_4	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TColi[b]	FColi[b]
ADT	<500	$\bar{X}$	280	21,600	153,000	1,500	3,440	8,335	-	3,470	2.8	198	89	21,700	1,210	384	26	19	232	1.3E6	6.9E4
		σ	343	-	-	-	-	-	-	-	2.0	76	37	9,300	1,100	130	23	15	100	2.0E6	1.6E5
		R	12-950	6,320-39,600	45,600-252,000	73-2,700	-	670-16,000	-	1,700-12,000	0 -5.4	132-295	33-130	13,000-43,000	280-3,900	210-620	7-75	3-33	110-420	8.4E4-5.0E6	3.0E2-6.5E5
		N	12	4	4	3	1	2	-	3	8	9	9	9	9	9	8	8	9	8	8
	500-5K	$\bar{X}$	140	9,500	83,000	741	212	419	-	1,315	2.9	196	107	10,900	1,060	415	17	34	410	2.1E6	3.4E5
		σ	155	8,520	83,200	950	-	209	-	846	1.6	62	31	3,500	925	140	18	32	198	2.5E6	4.6E5
		R	20-600	1,720-25,300	18,300-277,000	20-2,800	-	64-845	-	890-2,200	1.1-6.1	138-320	67-170	14,000-23,000	64-3,500	150-700	0-55	3-110	180-760	1.0E5-9.6E6	3.5E2-1.[illegible]
		N	24	16	16	15	1	11	-	7	12	12	12	12	13	12	11	12	12	17	16
	5K-15K	$\bar{X}$	146	27,400	163,000	1,340	2,980	836	2,640	2,900	3.8	215	107	22,500	2,010	442	30	10	375	3.1E6	1.7E5
		σ	211	26,000	165,000	1,250	1,070	979	1,820	2,430	2.3	80	62	10,000	1,480	172	35	10	167	7.1E6	2.0E5
		R	3-946	2,900-10,400	18,000-526,000	30-5,050	2,130-4,850	37-3,600	595-5,390	490-9,250	0.0-9.3	9-430	9-300	2,600-59,000	47-5,700	160-1,100	0-140	4-63	57-780	2.5E4-3.4E7	6.7E1-9.1E5
		N	61	38	42	43	5	37	9	[illegible]	56	54	56	56	54	55	58	51	54	37	33
	>15K	$\bar{X}$	82	5,720	26,980	514	-	501	-	1,600	3.1	203	102	22,900	2,230	357	28	18	389	3.0E5	1.4E5
		σ	104	-	-	-	-	-	-	-	2.1	93	69	13,400	1,5[illegible]0	105	23	11	160	5.4E5	2.1E5
		R	3-325	1,940-8,600	21,000-321,000	27-1,000	-	323-600	-	0	0 -6.8	24-345	25-250	1,400-53,000	470-5,100	100-500	4-83	5-38	150-720	1.0E4-2.0E6	1.2E2-5.2E5
		N	17	4	4	4	-	4	-	2	16	16	16	16	15	15	15	15	16	12	11
AREA BEYOND	1	$\bar{X}$	196	32,400	154,000	1,720	3,500	1,010	3,620	3,900	3.9	197	96	21,040	1,370	406	27	24	348	8.3E5	7.4E4
		σ	245	37,900	172,000	1,490	2,060	1,320	1,340	3,240	5.9	71	39	8,500	980	157	25	20	168	1.6E6	1.4E5
		R	8-950	2,100-16,700	18,300-526,000	100-5,790	212-5,440	37-3,600	1,080-5,390	890-11,900	0.0-8.8	63-345	23-190	8,100-53,000	117-3,900	130-1,100	0-96	3-93	110-880	4.0E4-9.4E6	3.0E1-5.7E5
		N	55	29	31	28	3	25	6	26	50	51	53	51	53	51	49	51	53	40	30
	2	$\bar{X}$	37	23,000	141,300	1,140	-	540	-	1,800	-	-	-	-	-	-	-	-	-	1.1E7	3.5E5
		σ	70	21,500	108,000	1,120	-	186	-	580	-	-	-	-	-	-	-	-	-	6.4E6	4.9E5
		R	19-96	2,900-67,300	24,500-312,000	28-3,300	-	482-940	-	1,200 2,700	-	-	-	-	-	-	-	-	-	3.9E5-8.6E7	7.0E3 1.3E6
		N	11	10	12	12	-	7	-	5	-	-	-	-	-	-	-	-	-	13	12
	3	$\bar{X}$	93	9,990	86,900	824	-	721	-	2,600	4.4	262	120	34,500	2,350	430	33	22	352	3.3E6	3.3E5
		σ	56	11,600	96,900	1,370	-	230	-	-	-	-	-	-	-	-	-	-	-	3.0E6	3.4E5
		R	4-153	2,030-24,300	24,600-277,000	20-3,200	-	356-981	-	1,600-3,600	1.6-8.8	210-264	48-210	19,000-59,000	1,700-3,000	290-500	7-45	0-33	410-460	3.1E5-9.6E6	7.0E3 1.0E6
		N	10	7	7	7	-	5	-	2	4	4	4	4	4	4	4	3	4	8	8
	4	$\bar{X}$	121	13,700	78,000	787	2,510	461	662	1,200	3.6	228	116	22,000	2,370	444	41	16	385	7.1E5	1.6E5
		σ	151	10,200	71,100	590	-	232	-	594	2.1	87	77	9,320	1,720	154	34	8	162	1.1E6	2.0E5
		R	4-800	2,180-35,000	21,000-224,000	30-1,800	2,130-2,770	72-790	595-730	365-1,600	0.4-8.8	9-430	16-300	2,600-42,000	17-5,700	250-870	4-120	0-37	57-720	1.0E4-4.0E6	7.2E1-9.7E5
		N	40	17	13	17	4	16	3	11	34	33	35	36	36	35	36	35	36	30	28

Table A-23 (continued)

			lbs/curb mi/day	Concentrations in Micrograms per Gram of Dry Solids																	No./grams	
Category	#		Loading	BOD_5	COD	OPO_4	TPO_4	NO_3	NH_4	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TColi[b]	FColi[b]
STREET SURFACE TYPE	1	$\bar{X}$	150	23,000	150,000	2,470	212	11,600	-	1,770	3.7	217	107	22,400	2,000	414	43	18	380	-	-
		σ	225	14,900	91,000	562	-	-	-	792	2.3	78	64	8,570	1,590	161	41	12	178	-	-
		R	4- 950	5,300- 43,900	49,000- 298,000	1,600- 3,000	-	-	-		0 - 8.8	71- 430	25- 300	11,000- 48,000	117- 7,600	210- 830	1.0- 170	3- 78	110- 890	-	-
		N	65	9	9	7	1	1	-	7	55	59	60	58	60	60	57	58	59	-	-
	2	$\bar{X}$	38	72,000	383,000	3,520	5,150	2,600	3,620	6,680	3.5	173	97	22,800	1,280	342	24	45	292	-	-
		σ	17	51,700	163,000	1,730	-	920	1,340	3,940	2.9	100	31	13,300	814	154	15	38	116	-	-
		R	16- 69	19,000- 175,000	114,000- 611,000	1,600- 6,670	4,850- 5,440	1,810- 4,400	1,880- 5,390	1,900- 12,800	0.6- 9.3	24- 305	64- 150	8,100- 33,000	230- 2,500	100- 520	1- 55	6- 110	160- 480	-	-
		N	16	13	13	11	2	7	6	13	10	11	11	10	10	10	10	11	10	-	-
ALL DATA		$\bar{X}$	156	19,900	140,000	1,280	2,930	804	2,640	2,950	3.4	211	104	22,020	1,805	418	35	21	370	2.5E6	1.7E5
		σ	220	19,800	155,000	1,440	1,750	977	1,820	2,850	2.3	90	58	9,980	1,290	130	33	17	170	5.7E6	2.9E5
		R	4- 950	2,100- 78,900	18,000- 611,000	14- 6,670	212- 5,440	45- 3,600	593- 5,390	450- 10,500	0 - 9.3	5- 385	9- 300	2,200- 59,000	47- 5,700	160- 830	0- 140	0- 78	57- 880	1.0E4- 3.4E7	6.7E1- 1.2E6
		N	119	60	68	69	7	53	9	44	91	93	93	93	89	88	93	89	91	95	88

a = Blanks indicate that no data were available.

b = Coliform counts are expressed in computer notation, i.e., E6 = 10^6.

indicates a range of ten percentage units. These transformations are carried over into Table A-24, which shows the means and the subscripts described. It is intended here that the percent standard error of the mean represents the confidence that may be placed in the value of the mean for predictive purposes. Subscripts are not given for mean values of less than five data points.

Table A-24 is constructed so that the total degrees of freedom available in making a statistical test of significance exceeds ten. The Student t probability distribution is relatively constant for degrees of freedom of 10 or greater, so all discussion which follows is based on 10 degrees of freedom.

Table A-24 may be used directly for detecting functional relationships between dependent and independent parameters by the simple mechanism of the Student t test for significance, described in the next section. For example, referring strictly to the Loading column in Table A-24, the following statements can be made: (1) commercial and residential area means are different at the 97 percent confidence level, (2) commercial and light industrial area means are different at only the 73 percent confidence level, (3) commercial and heavy industrial area means are different at the 95 percent confidence level, and (4) the commercial mean differs from the mean of the set of all data at the 98 percent confidence level. These four statements were proved within two minutes by the author, using a hand electronic calculator and a plot of the Student t distribution. Obviously Table A-24 is an extremely useful and versatile tool in predicting functional relationships between the dependent and independent parameters in this study.

The information in Table A-24 is presented in a more useful fashion in the text as Tables 5, 6, and 7. These tables show only those subset means which differ from the means of the set of all data at the 95, 90, and 80 percent confidence levels, respectively. These tables enable the

Table A-24. MEANS AND PERCENT STANDARD ERRORS OF THE MEANS (Subscripts[a]) OF THE SET OF ALL DATA AND OF 19 SUBSETS OF THE DATA

	Category		lbs/curb mi/day	Concentrations in micrograms per gram of dry solid																No./gram	
			Loading	BOD$_5$	COD	OPO$_4$	TPO$_4$	NO$_3$	NH$_4$	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TCOLI[b]	FCOLI[b]
Land Use	10	Open space	12	20,300	171,000	1,700	5,440	16,000		7,250	0.6	5	9	2,600	15		6		22	1.6E5	7.1E3
	20	Residential	149$_b$	14,000$_b$	82,000$_b$	850$_b$	2,000$_c$	550$_c$	660	1,800$_a$	3.0$_b$	192$_a$	93$_a$	20,600$_a$	1,430$_b$	392$_a$	28$_b$	21$_b$	350$_a$	1.7E6$_c$	1.6E5$_c$
	30	Commercial	74$_c$	58,700$_c$	269,000$_c$	2,250$_c$	4,850	1,580$_c$	3,620$_b$	6,430$_b$	4.2$_b$	225$_b$	133$_b$	23,300$_b$	3,440$_b$	397$_a$	48$_b$	18$_b$	520$_b$	1.8E6$_e$	1.9E5$_d$
	40	Light industry	389$_f$	27,300	180,000	1,275		430		1,750	4.0$_c$	288$_d$	128$_b$	21,800$_a$	2,780$_d$	490$_b$	41$_d$	27$_d$	368$_b$	2.1E6$_f$	1.3E5$_f$
	50	Heavy industry	203$_c$	12,100$_e$	88,000$_e$	1,250$_d$		246$_e$		1,420$_b$	3.9$_b$	278$_b$	107$_b$	28,600$_b$	1,160$_c$	570$_b$	37$_c$	23$_c$	317$_b$	8.2E5$_e$	1.8E5$_f$
Climate	1	Northeast	291$_c$	29,100$_c$	159,000$_c$	990$_d$	3,390$_b$	1,010$_b$	2,640$_c$	5,970$_c$	2.6$_b$	139$_b$	99$_b$	17,700$_b$	870$_c$	363$_a$	21$_c$	27$_b$	260$_b$	1.8E6$_b$	4.4E5$_c$
	2	Southeast	103$_b$	29,100$_b$	172,000$_b$	2,240$_a$	212	43		1,970$_a$	4.0$_b$	234$_b$	137$_b$	20,300$_b$	1,370$_b$	395$_b$	21$_b$	28$_b$	439$_b$	1.9E6$_e$	7.0E4$_d$
	4	Southwest	50$_e$	11,700$_b$	139,000$_c$	470$_b$		1,160$_d$		2,400$_b$	3.8$_b$	241$_a$	76$_a$	22,600$_a$	2,520$_b$	446$_a$	57$_b$	15$_a$	357$_a$	5.7E6$_d$	5.2E5$_f$
	5	Northwest	30$_c$	10,000	38,000	1,100		59		5,000	1.8$_b$	246$_a$	96$_c$	34,500$_b$	2,600$_b$	455$_a$	35$_a$	10$_c$	480$_a$	6.8E5$_f$	1.1E4$_f$
Average Daily Traffic No./day	<	500	280$_d$	21,600	153,000	1,500	5,440	8,330		5,470	2.8$_c$	198$_b$	80$_b$	21,700$_b$	1,210$_d$	384$_b$	26$_d$	19$_d$	252$_b$	1.3E6$_f$	6.9E4$_f$
		500 - 5,000	140$_c$	9,500$_e$	83,000$_e$	793$_d$	212	419$_b$		1,515$_c$	2.9$_b$	196$_a$	107$_a$	18,900$_a$	1,060$_c$	415$_b$	17$_d$	37$_c$	418$_b$	2.1E6$_c$	3.4E5$_d$
		5,000 - 15,000	146$_b$	27,400$_b$	163,000$_b$	1,340$_b$	2,980$_b$	836$_b$	2,640$_e$	2,900$_b$	3.8$_a$	215$_a$	107$_a$	22,500$_a$	2,010$_b$	442$_a$	38$_b$	18$_a$	375$_a$	3.1E6$_d$	1.7E5$_c$
	>	15,000	82$_d$	5,720	26,980	514		501		1,600	3.1$_b$	203$_b$	102$_b$	22,900$_b$	2,230$_b$	357$_a$	28$_c$	16$_b$	389$_b$	3.8E5$_e$	1.4E5$_e$
Type of Landscaping Beyond the Sidewalk	1	Grass	196$_b$	32,400$_c$	154,000$_c$	1,720$_b$	3,500	1,010$_e$	3,620$_b$	3,900$_b$	3.9$_e$	197$_a$	96$_a$	21,000$_a$	1,370$_b$	406$_a$	27$_b$	24$_b$	348$_a$	8.3E5$_d$	7.4E4$_d$
	2	Trees	43$_b$	23,000$_d$	142,000$_c$	1,140$_c$		540$_b$		1,800$_b$										1.1E7$_b$	3.3E5$_e$
	3	Landscaped buildings	93$_b$	9,990$_e$	86,900$_e$	824$_f$		721$_b$		2,600	4.4	243	130	34,500	2,350	430	33	22	552	3.5E6$_d$	3.5E5$_d$
	4	Hard surfaces	121$_c$	13,700$_b$	78,000$_e$	787$_b$	2,510	461$_b$	662	1,200$_b$	3.6$_b$	228$_a$	116$_b$	22,000$_a$	2,370$_b$	446$_a$	41$_b$	16$_a$	385$_a$	7.1E5$_c$	1.6E5$_d$
Street Surface Material	1	Asphalt	150$_b$	23,000$_c$	150,000$_c$	2,470$_a$	212	11,600		1,770$_b$	3.7$_a$	217$_a$	107$_a$	22,400$_a$	2,000$_b$	414$_a$	43$_b$	18$_a$	380$_a$		
	2	Concrete	38$_b$	72,000$_c$	383,000	3,520$_b$	3,150	2,600$_b$	3,620$_b$	6,680$_b$	3.5$_c$	173$_b$	97$_b$	22,800$_b$	1,280$_c$	342$_b$	24$_c$	45$_c$	292$_b$		
		All data	156$_b$	19,900$_b$	140,000$_b$	1,280$_b$	2,930$_c$	804$_b$	2,640$_e$	2,950$_b$	3.4$_a$	211$_a$	104$_a$	22,000$_a$	1,810$_a$	418$_a$	35$_a$	21$_a$	370$_a$	2.5E6$_c$	1.7E5$_b$

[a] Percent Standard Error of the Mean Subscripting Code: a = 0 - 9, b = 10 - 19, c = 20 - 29, d = 30 - 39, e = 40 - 49, f = 50 - 62.

[b] Coliform counts are expressed in computer notation, i.e., E5 = 10^5.

planner to find quickly the best data available in predicting loading rates and chemical composition. The use of these tables is described in detail in the text.

An urban planner may be concerned whether or not one mean value is significantly different from another. Table A-24 is constructed so that he may perform a Student t test of significance, some example results of which were mentioned in the last section,

The table is constructed so that (1) the standard error of the mean falls into a group which has numerical limits as narrow as feasible while still permitting efficient presentation, and (2) standard errors of the mean are presented only for those values where the number of samples was five or greater, so that the degree of freedom used when consulting tables or graphs of the Student t distribution is always greater than ten. All discussion is based on 10 degrees of freedom.

The Student t is performed as follows:

Definitions

σ = standard deviation

$\overset{*}{\sigma}$ = standard error of the mean

$$\overset{*}{\sigma} = \frac{\sigma}{\sqrt{n}} \text{ for } n > 10 \text{ and } \frac{\sigma}{\sqrt{n-1}} \text{ for } n < 10$$

$\%\overset{*}{\sigma}$ = percent standard error of the mean; this is the value indicated by superscript in the tables

$$\%\overset{*}{\sigma} = (\overset{*}{\sigma}/\bar{x}) \quad 100$$

$\bar{x}$ = sample mean

σ_ω = standard error of the difference

First, compute the standard error of the difference between any two means, $\bar{x}_1$ and $\bar{x}_2$, as

$$\sigma_\omega = \sqrt{\sigma_1^{*2} + \sigma_2^{*2}}$$

Then the Student t is defined as

$$\text{Student t} = \frac{\bar{x}_1 - \bar{x}_2}{\sigma_\omega}$$

The probability that the Null Hypothesis (that $\bar{x}_1 - \bar{x}_2 = 0$) is correct is given in tables of the Student t distribution listed in any good statistics text or in Standard Mathematical Tables (Chemical Rubber Publishing Company, Cleveland, Ohio).

To assist the planner in learning and using this technique, two sample problems are presented:

Problem 1:

Question: Is the mean COD concentration in solids found in heavy industrial areas significantly different from that found in residential areas?

Given: (1) Heavy Industry COD = $88{,}000_e$

(2) Residential COD = $82{,}000_b$

Subscript e = 40-50%, average 45%

Subscript b = 10-20%, average 15%

$\overset{*}{\sigma}_1 = 80{,}000 \times 0.45 = 36{,}000$

$\overset{*}{\sigma}_2 = 82{,}000 \times 0.15 = 12{,}300$

$\sigma_\omega = \sqrt{36{,}000^2 + 12{,}300^2} = 38{,}000$

$\text{Student t} = \dfrac{2{,}000}{38{,}000} = 0.05$

Consulting tables of Student t with 10 degrees of freedom, the probability that the Null Hypothesis is true is >0.90. Therefore, there is no significant difference between these mean values. Using the original data, Student t is calculated as 0.048 and the same conclusion is arrived at: that the difference in the means is not significant.

Problem 2:

Question: Is the mean Pb concentration in solids from areas with ADT>15,000 larger than from areas with ADT 500-5000?

Given: Pb @ ADT = 500-5000 = 1060_c
Pb @ ADT>15,000 = 2230_b
Subscript c = 20-29% average = 25%
Subscript b = 10-19% average = 15%
$\overset{*}{\sigma}_1 = 1060 \times 0.25 = 265$
$\overset{*}{\sigma}_2 = 2230 \times 0.15 = 334$
$\sigma_\omega = \sqrt{265^2 + 334^2} = 427$
Student t $= \frac{2230 - 1060}{427} = \frac{1170}{427} = 2.74$

Consulting tables of the Student t distribution with 10 degrees of freedom, the probability of the Null Hypothesis' being correct is 0.020. Therefore, the difference is significant at the 98 percent confidence level. Using the original data, Student t is calculated as 2.53 and the confidence level of the difference is actually 97 percent rather than 98 percent. The decision remains the same, however. The difference in the means is highly significant.

4. Conclusions Obtained in the Data Processing

Table A-24 provides the mechanism for detecting significant functional relationships between independent and dependent parameters. Some of these relationships observed by the authors are put forward here. It should be realized that these conclusions are derived from data which represent the combined effects of natural physical processes and man's activities. Sweeping the streets, for example, logically reduces the apparent loading rate recorded here but does not change the rate of the natural accumulating process, a parameter which cannot be measured by the methods used in this study. These conclusions represent the state of the nation resulting from normal mean living conditions. Unexpected findings are noted with an asterisk (*).

a. Loading Rates Are Lowest in:

1. Commercial areas, probably because they are swept frequently
2. Northwest
3. Areas with highest traffic, probably because the removal processes (primarily traffic generated winds) are more active

*4. Tree covered areas; unexpected because it was thought that leaves contributed substantially to loading rates

5. Concrete surfaces

b. BOD_5 Concentrations Are Lowest in:

1. Residential and heavy industrial areas
2. The southwest, probably reflecting the lack of lush vegetation relative to the East Coast
3. Areas with moderate ADT
4. Areas with landscaped buildings, probably reflecting better maintenance
5. On asphalt road surfaces

c. COD Concentrations Are Lowest in:

1. Residential and heavy industry, whereas it is highest in commercial areas; the latter may be due to oil from many parked cars on the street
2. Not significantly different climatologically
3. Areas with moderate traffic (500-5000 ADT)
4. Areas with landscaped buildings
5. Not significantly different between street surface types

d. Ortho Phosphate Concentrations Are Lowest in:

*1. Residential areas; an unexpected finding considering the widespread use of fertilizer on lawns

2. The southwest (highest in southeast), probably reflecting the difference in vegetation or fertilizing practices
3. Areas with moderate traffic (500-5000 ADT)
4. Areas with no landscaping, probably because no fertilizer is used
5. On asphalt surfaces

e. No Conclusions Can Be Obtained From the Total Phosphate Data

f. Nitrate Concentrations Are Lowest in:

1. Heavy industry areas
2. No significant differences climatologically
3. No significant differences between traffic densities
4. Areas without landscaping
5. No significant difference between street surface types

g. No Conclusions Can Be Obtained from the Ammonia Data

h. Organic Nitrogen Concentrations Are Lowest in:

  1. Heavy industry areas
  *2. The southeast; and unexpected finding since the southeast contains the most lush vegetation
  3. Areas with moderate traffic (500-5000 ADT)
  4. Areas without landscaping
  5. Asphalt surfaces

i. Cadmium Concentrations Are Relatively Uniform in All Categories

j. Chromium Concentrations Are Lowest in:

  1. Residential areas
  *2. The northeast; unexpected since the major source of chromium on streets was thought to be chromate salts added to deicing salt as a metal preservative
  3. No significant differences with traffic density
  4. No significant difference with landscaping
  5. On concrete surfaces

k. Copper Concentrations Are Lowest in:

  1. Residential areas
  2. The southwest
  3. Areas with light traffic (<500 ADT)
  4. Areas with grass landscaping
  5. Not significantly different between street surface types

l. Iron Concentrations Are Lowest in:

  1. Not significantly different with land use types
  *2. Lowest in the northeast (highest in northwest)
  3. Not significantly different with traffic density

4. Not significantly different with landscaping type

5. Not significantly different between street surface types

m. Lead Concentrations Are Lowest in:

1. Heavy industry areas, low also in residential areas; this probably reflects low vehicular traffic

*2. The northeast (highest in the northwest); this may reflect the inhomogeneity of sampling sites

3. Areas with light and moderate traffic

4. Areas with grass landscaping

5. Concrete road surfaces

n. Manganese Concentrations Do Not Vary Greatly Between Categories

o. Nickel Concentrations Are Lowest in:

1. Residential areas

2. The northeast and southeast

3. Areas with moderate traffic (500-5000 ADT)

4. Areas with grass landscaping

5. Concrete road surfaces

p. Strontium Concentrations Vary Only Slightly Between Categories

q. Zinc Concentrations Are Lowest in:

*1. Heavy industry areas

2. The northeast

3. Areas with light daily traffic ($<$500 ADT)

4. Not significantly different between landscaping types

5. Concrete surfaces

r. Total Coliform Counts are Lowest in:

1. Heavy industry areas
2. The northwest
3. Areas with heavy vehicular traffic (>15,000 ADT)
4. Areas with grass or no landscaping (and highest in tree covered areas)

s. Fecal Coliform Counts Are Lowest in:

*1. No significant differences between land use categories; unexpected because generally it is thought that pet feces cause higher fecal coliform counts in residential areas

2. The northwest
3. Areas with heavy traffic (>15,000 ADT)
4. No significant differences with landscaping

Generally the trends observed were expected, or, at least, not unexpected. In eight cases the data indicated that preconceived notions were not supported by observations.

5. Summary

The URS staff has assembled all presently available data on the rates of accumulation of solids and the concentrations of various constituents in those solids that collect on street surfaces. These data have been grouped and processed into a form which should be useful to an urban planner in predicting the pollutional load from areas projected for urban development.

The range and scatter in the available data are extreme. Both the sampling variability and the complexity of natural systems contribute to this extreme variance. Attempts to test conceptual models with the available data have met with absolutely no success because the models are much too simple to adequately describe the conditions in the real world. The available data records are not sufficiently complete to permit sophisticated analyses of covariance.

The data and calculations presented here represent the state-of-the-art, as viewed by the participants in this study, on the subject of loading rates and chemical composition of solids on streets. The results presented here are probably adequate for most urban planning operations. As the nation becomes more concerned in the future over nonpoint sources of pollutants, more sophisticated models of accumulation rates should be developed and tested. The methods of sample collection and analysis should be standardized. Controlled experiments should be carried out in an effort to identify sources of solids loading. These adjustments in the state-of-the-art will permit refinements in the methods of handling data as presented here.

Appendix B

SAMPLING PROCEDURE

Appendix B

SAMPLING PROCEDURE

In many instances, local agencies may want to conduct sampling and analytical programs of their own. These data, if handled properly, may be used in analyzing the areas' runoff problems instead of using values presented in the manual. This would be desirable in most instances, but especially in areas or under specific conditions that were not analyzed in great detail under any studies used in preparing this manual.

Additional information is presented in the following discussion to help these local agencies design and carry out sampling programs of their own. The first question to be answered concerns the type of sampling to be conducted. Two general types have been used in the studies referenced in this manual. These are the street surface collection method and the runoff collection method. Both methods require a substantial amount of additional information concerning the area. The street surface method has an advantage of being able to conduct sampling without having to wait for rain and the elaborate rainfall data required for the runoff sampling method.

The following list briefly describes the procedures which may be used in a street surface sampling program.

LOCALITY DATA COLLECTION

After setting up traffic control in the chosen test area, information should be gathered as to: location, date, land use, parking and traffic characteristics; street, gutter, and curb composition, condition and texture; test area and description of the adjoining area. At this time photographs of the area should be taken. Street cleaning and rainfall history of the test site is highly desirable.

HAND SWEEPING

Hand sweeping, or dry solids collection, should utilize a standard stiff bristled broom, sweeping toward the curb while moving laterally along the street. After concentration in the gutter, samples should be collected by whisk broom and dustpan and placed in clean paint cans.

HOSE FLUSHING

Flushing should be conducted after sweeping to remove adherent soluble films and otherwise nonsweepable material. The downslope gutter should be dammed with sandbags to create a collection area for flushing water. A small vacuum collector can be constructed using 5-gal paint cans and connected to an industrial wet/dry vacuum cleaner. The test area is first slightly wetted to facilitate removal of soluble materials. Flushing should be commenced at the road crown, using a garden hose and spray nozzle connected to fire hydrants. All water is collected by the vacuum box and measured. The samples then are mixed by vigorous stirring and split to a 1-gal volume. If pesticide analysis is to be conducted, an additional sample should be taken in quart size glass containers. Plastic gallon bottles may be used for all other samples.

Collecting rainfall runoff samples will give a definite indication of the concentration of contaminants in the runoff, but collecting representative samples can be difficult. Relating these runoff concentrations to other instances (differing rainfall intensity patterns, etc.) can be nearly impossible. In some cases, this procedure may be preferred, and the following general instructions may be helpful.

DATA COLLECTION

Land use patterns within the watershed must be clearly defined. Percentages of vacant land and special sources must be identified and located. Accurate distribution of rainfall intensity is also required. Street cleaning and rainfall history of the area is highly desirable.

SAMPLE COLLECTION

Sample collection should begin at the onset of a rain event and continue for as long as practicable (at least several hours). Accuracy would be enhanced by collecting discrete samples based on volume of flow and not by time. Besides collecting samples, flow data should be compiled. If pesticide analyses are to be conducted, the sample containers should be glass.

SAMPLE HANDLING AND PREPARATION PROCEDURES

All solids and liquid samples should be immediately shipped from the test sites to the laboratory. Upon receiving the shipment, the samples must be placed in a cold room maintained at 5°C. The solids can be stored in new unlined metal paint cans, while the liquids can be stored in plastic containers. All samples designated for pesticide analysis must be collected and stored in glass containers.

All individual solid samples should be dried under heat lamps (less than 100°F) and weighed.

Size classification of solid samples is performed by standard sieve analysis. The dried solid sample to be analyzed is placed on top of the 2000-micron screen in the nest of 5 screens (sizes 2000 microns, 840 microns, 246 microns, 104 microns, 43 microns and the pan). The screens are then placed in a roto tap unit and agitated for a half hour. The screens are then removed and the material on each screen weighed.

Special sample preparation should be used for the heavy metal analysis of the liquid samples. All liquid samples can be cotton filtered prior to analysis to remove large settleable solids.

SOLID SAMPLE PREPARATION

Prior to chemical analysis aliquots of each solid composite sample can be taken and placed in a blender with a known amount of distilled water (varied according to strength of pollutant) and homogenized.

Appendix C

BIBLIOGRAPHY

Appendix C

BIBLIOGRAPHY

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1															X		computer techniques for runoff amounts
2		X				X	X	X			X	X					
3	Ohio	X			X							X					persistence of bacteria
4	Michigan	X										X					also information for separate sewer systems
5																X	summary of treatment necessary to achieve specific quality
6	U.S.S.R.	X					X	X			X						
7	Washington	X				X	X	X					X			X	highway runoff
8																X	summary of treatment necessary to achieve specific quality
9	Michigan	X				X	X	X									also information for separate sewer systems
10																X	deep tunnel storage
11	No. California	X					X	X							X		
12	U.S.			X		X	X		X								
13	Maryland						X										urbanization effects
14															X		urbanization effects
15	U.S.										X						good information on deicing compounds and application procedures
16	Kansas					X	X	X									urbanization effects
17																	urbanization effects
18	New York			X					X								
19						X	X	X			X						amounts of deicing material used in United States
20																X	storm standby tanks for storage
21																X	existing practices in 5 cities
22																X	freeway runoff treatment
23																X	high rate filtration
24															X		computer technique for hydrograph development
25																X	porous pavements and hydrology effects
26	No. California			X					X								lead near roadways
27	Michigan								X					X			mercury in soils
28	So. California														X		
29	Ohio	X			X	X	X	X		X	X	X					
30	Arizona	X				X	X	X				X		X		X	
31	No. Carolina	X				X	X	X	X	X	X	X		X			
32	New Jersey																effects of urbanization on flow quantity
33																X	stilling ponds
34	Georgia	X				X	X	X				X	X				
35	Louisiana															X	disinfection at New Orleans
36	Oklahoma	X				X	X	X				X	X	X			
37	Washington, D.C.																highway drainage runoff
38	U.S.		X						X	X				X			
39																X	
40																X	
41	Ohio	X		X		X	X	X				X		X			
42																	review of effects of urbanization on hydrology
43	Illinois	X			X	X	X	X									effects on Lake Michigan
44	Maryland														X		
45	U.S.		X			X	X	X	X	X		X	X	X		X	major study throughout United States, many analyses
46	Illinois		X			X	X	X				X					basic study
47																X	review paper of general characteristics of runoff

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Appendix D

GLOSSARY

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1. **Ammonia Nitrogen (NH_4)** - a form of nitrogen which is an essential nutrient to plants (can cause algal blooms if all nutrients are present in sufficient quantities). A product of natural decomposition of fecal matter, urea and other animal protein.

2. **Average Daily Traffic (ADT)** - an average value for the daily vehicular traffic on a specific roadway.

3. **Biochemical Oxygen Demand (BOD_5)** - the amount of oxygen required by bacteria in a five day period while decomposing organic matter under aerobic conditions.

4. **Cadmium (Cd)** - an element of high toxic potential when taken by mouth and possible association with renal arterial hypertension at sublethal levels.

5. **Chemical Oxygen Demand (COD)** - a determination of organic material. The sample is "completely" oxidized by chemical methods, instead of the incomplete oxidation by bacteria in the BOD_5 test.

6. **Chromium (Cr)** - a toxic element when present in the hexavalent chromium ion form.

7. **Copper (Cu)** - an essential and beneficial element in human metabolism, but quantities above 1 mg/ℓ tend to impart an undesirable taste to drinking water.

8. **Cubic Feet Per Second (cfs)** - one cubic foot volume of water passing a point per unit second.

9. *DDD* - an organochlorine insecticide [1,1-dichloro-2, 2-*bis*-(*p*-chlorophenyl) ethane].

10. *DDT* - an organochlorine insecticide closely related to DDD [1,1,1,-trichloro-2, 2-*bis*-(*p*-chlorophenyl) ethane].

11. *Dieldrin* - an organochlorine insecticide of fairly complex molecular structure.

12. *Dissolved Oxygen (DO)* - the amount of oxygen dissolved in a liquid. If at equilibrium with the overlaying atmosphere, it is then considered saturated. Must be present to support aerobic aquatic life. Is consumed naturally in the "self-purifying" process of waterways.

13. *Endrin* - an organochlorine insecticide which has the same structural formula as dieldrin and is its isomer.

14. *Equivalent Days of Accumulation (EDA)* - a measure of the relative days of accumulation of pollutants on a street surface as a function of rainfall and sweeping history and respective removal efficiencies.

15. *Fecal Coliforms (FColi)* - indicators of recent fecal pollution in water supplies by pathogenic bacteria, expressed as number of organisms per gram of solids of street surface material.

16. *Iron (Fe)* - an element that imparts a bitter taste to water and a brownish color to clothing laundered in such water.

17. *Lead (Pb)* - a highly toxic heavy metal when ingested for either brief or prolonged periods (cumulative poison).

18. *Lindane* - an organochlorine insecticide which is the gamma isomer of benzene hexachloride.

19. Loading - the average amount of total solids found on street surfaces per unit distance per day (i.e., pounds/curb mile/day).

20. Manganese (Mn) - an element which produces a brownish color in laundered goods and impairs the taste of beverages, including coffee and tea.

21. Mercury (Hg) - a heavy metal which can cause severe neurological disorders when it is ingested in large quantities. (Particularly dangerous because small quantities can be concentrated by aquatic organisms which are frequently eaten by man).

22. Methoxychlor - an organochlorine insecticide [1,1,1-trichloro-2, 2-*bis* (*p*-methoxyphenyl) ethane].

23. Methyl Parathion - an organophosphate insecticide [0,0-dimethyl 0-*p*-nitrophenyl phosphorothioate].

24. Micron (μ) - a unit of length equal to 1 x 10^{-6} meters.

25. Micrograms Per Gram (μg/g) - the micrograms of a specific pollutant found per gram of total solids.

26. Micrograms Per Kilogram (μg/kg) - the micrograms of a specific pollutant found per kilogram of total solids.

27. Milligrams Per Liter (mg/ℓ) - the milligrams of a substance per liter of water on a dry weight basis.

28. Most Probable Number (MPN) - a statistical indication of the number of bacteria present in a given volume (usually 100 mℓ).

29. **Nickel (Ni)** - an element which is very toxic to most plants (especially agricultural crops) but less so to animals.

30. **Nitrate (NO_3)** - a form of nitrogen which is an essential nutrient to plants (can cause algal blooms if all other nutrients are present in sufficient quantities). Product of bacteria oxidation of other forms of nitrogen, from the atmosphere during electrical storms and from fertilizer manufacturing.

31. **Organic Nitrogens (OrgN)** - "original" form of nitrogenous nutrients. Gradually converted to ammonia nitrogen and to nitrites and nitrates, if aerobic conditions prevail. An indication of algal activity potential of a water.

32. **Orthophosphate ($OPO_4^{\equiv}$)** - a measure of the total inorganic phosphate content. Other inorganic phosphate forms (polyphosphate) convert to this form after several hours to several days. Inorganic phosphate is an important nutrient to plants, and excessive amounts can cause algal blooms if the right conditions prevail.

33. **Polychlorinated Biphenyls (PCB)** - organochlorine compounds of a pesticidal nature which are usually used for industrial purposes (such as plastic manufacture).

34. **Pounds Per Curb Mile (lb/curb mile)** - a measure of loading intensity of a pollutant per unit distance.

35. **Strontium (Sr)** - the radioactive form of this element (Strontium-90) has a tendency to accumulate in bone structures and is a well-recognized health hazard.

36. Total Coliforms (TColi) - bacterial indicators of less recent pollution and/or the existence of defects in water treatment or distribution (these bacteria are of nonfecal origin usually originating in soil).

37. Total Phosphorus (TPO_4) - shows all types of phosphorus occurring in a water system (ortho-, poly- and organic) and is a good indicator of the potential biological productivity of the water.

38. Zinc (Zn) - an essential element in human health which, when present in excess, can impart a milky appearance and metallic taste to water supplies. Is toxic to many organisms in large quantities.